Arnold Schwarzenegger
Governor

ADVANCED SWITCHES FOR SOFT BLACKOUTS CRITICAL INFRASTRUCTURE PROTECTION UNANTICIPATED DISCOVERY OF EMERGENCY VOLTAGE REDUCTION FOR GRID PROTECTION

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
The CSU, Chico Research Foundation
Willard H. Wattenburg

JUNE 2006
CEC-500-2006-058

Prepared By:
The CSU, Chico Research Foundation
Willard H. Wattenburg
Chico, CA
Contract No. 500-00-018

Prepared For:
California Energy Commission
Public Interest Energy Research (PIER) Program

Mark Rawson
Contract Manager
Energy Systems Integration
Program Area Team Lead

Martha Krebs, Ph. D.
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

B.B. Blevins
Executive Director

Table of Contents

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.
-

What follows is the final report for the Advanced Switches for "Soft" Blackout, Contract 500-00-018 conducted by the Research Foundation, California State University, Chico. The report is entitled Final Report. This project contributes to the Energy Systems Integration program area.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

All work supported by this contract was directed toward protecting the electrical gird from blackouts during power emergencies and attacks by terrorists using big trucks carrying explosive material. These were the two main threats to the stability of the energy supply for the citizens and businesses of California that existed or were identified in 2001. These threats continue today. The original one-year contract was for the testing and evaluation of a Load Reduction Switch that can produce "Soft Blackouts." Circumstances allowed the original contract funds to support the completion of two more major tasks over four years, as described below. The research performed under this contract produced the following deliverables:

- **The Load Reduction Switch**. A production version of an inexpensive Load Reduction Switch (LRS) was invented by W.H. Wattenburg before this contract was awarded. The LRS reduces the power used by a typical home by up to 80% when the switch is activated by remote control during a power emergency. The LRS was tested with a elaborate test set consisting of all the electrical appliances and devices found in two modern three-bedroom homes plus equipment commonly found in small commercial businesses. A completed pre-production version of a power meter based Load Reduction Switch is shown and described in Appendix I. The estimated cost per unit for quantities over 1,000 is $150. This LRS could have been manufactured in large numbers and installed before the summer of 2002 had the California energy crisis continued. (see Figure 1 below) All versions of the LRS are covered by U.S. U.S. Patent # 6,670,728 issued on December 30, 2003. All rights to this patent were assigned by the inventor, W.H. Wattenburg, to the state of California through the Research Foundation, CSU Chico.

Figure 1 Side view of the meter-based LRS unit (left) held next to a standard power meter (right). The meter base engaging plugs can be seen on the right side of the LRS unit. This LRS is inserted between the meter and the meter base. It can be installed by utility meter maintenance personnel. No special technical training is required. The round part of the LRS that can be seen below the hand holding it is the section of the LRS that contains the activation signal receiving electronics. The LRS shown here can receive standard pager messages that contain coded signals to activate or de-activate the LRS.

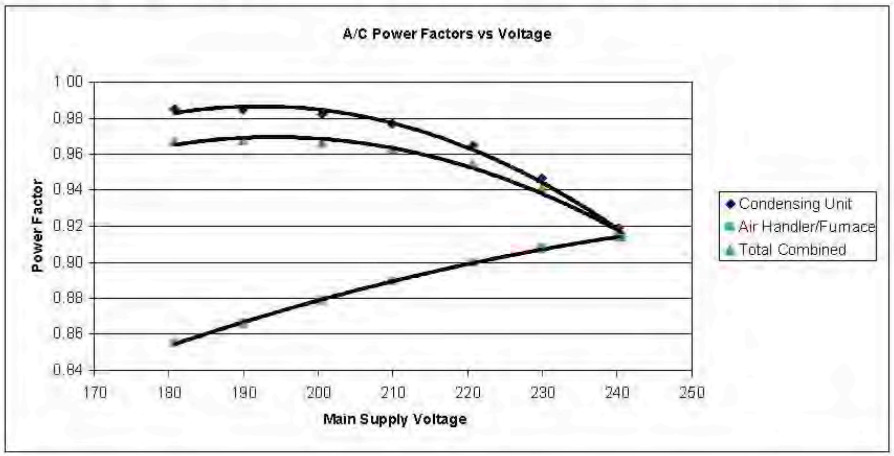
- **Emergency Voltage Reduction.** This was an unanticipated discovery that came out of the Load Reduction Switch laboratory testing in April and May 2001. A plan called **Emergency Voltage Reduction (EVR)** was suggested by the principal investigator and recommended by the ENERGY COMMISSION to the governor's office to avoid regional rotating blackouts at the height of the California energy crisis in June 2001. The EVR plan was based on the extensive low voltage test data that came from the Load Reduction Switch project. Surprisingly, all modern appliances, air conditioners, and business equipment tested performed well at voltages down to 105 volts. **The efficiency of all appliances and motors tested was better at 110 volts than at the standard 120 volts that most utilities supply to their customers. Most important of all, the equipment used less energy at lower voltages. This meant that significant load reduction could be achieved by dropping voltage on utility distribution lines a few volts during power emergencies (no lower than 114 volts). Field tests on fully loaded utility distribution lines in Los Angeles showed power reductions of 2% for voltage reduction of 5%, as predicted from the previous laboratory tests.** In meetings with the ENERGY COMMISSION and the governor's office in late June 2001, the three major investor owned California utilities agreed that they could reduce the load on the grid by 250 to 300 megawatts by lowering distribution line voltages by 2 ½% in portions of their systems (but no lower than 117 volts) during power emergencies. The utilities agreed to use EVR during future stage 3 power emergencies if the California Public Utilities Commission (CPUC) would protect them from customer complaints. The governor announced on July 3, 2001, that he wanted the CPUC to order the use of EVR during power emergencies. It was not necessary. The energy crisis ended on July 7, 2001. There were no more stage 3 power emergencies and no more threatened rotating blackouts for the rest of the year. (see Appendix IV for full history, test data, and discussion.)

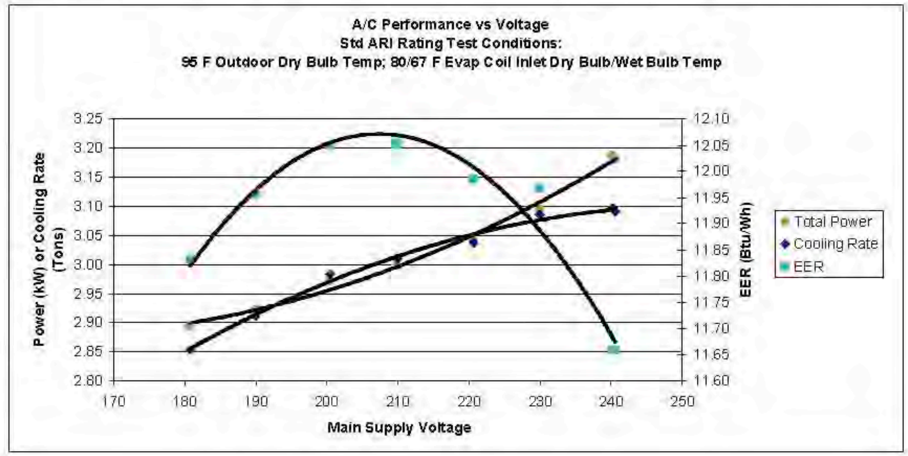
Modern home air conditioners are typical of the power reduction available with lower voltage. They are a very big domestic load on the gird during most peak demand times. The combined data table and graph below labeled "A/C Performance vs Voltage" show the overall performance of a typical modern air conditioner unit at voltages from 240 volts down to 180 volts. Note that the voltage at which the maximum EER (overall air conditioner performance factor, last column) occurs is 210 volts, not 240 volts. This means that a tremendous amount of energy is being wasted by operating millions of these air conditioners at the excessively high 240 volts. There is no question that a big reduction in load on a grid can be achieved simply by lowering distribution line voltages a few volts.

Notice that the power savings by operating this air conditioning unit at 230 volts is 2.7%. It is 4.4% at 220 volts. And the power demand reduction is 5.8% at 210 volts.

Performance Test Results for A/C Unit versus voltage

	Evap Inlet Air Temp		Evap Outlet Air Temp		Evap Outlet Static Pressure	Evap Air Flow	Condenser Inlet Air Temp		Cond Air Flow	Compressor / Motor Shell Temp	Condensing Unit Power					Air Handler/Furnace Power					Combined Power			Performance	
Date	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb			Dry Bulb	Wet Bulb			Voltage	Current	Power		Power Factor	Voltage	Current	Power		Power Factor	**Power**	kVA	Power Factor	Cooling Rate	**EER**
	(ºF)	(ºF)	(ºF)	(ºF)	(IW)	(ACFM)	(ºF)	(ºF)	(ACFM)	(ºF)	**(V)**	(Amps)	(kW)	(kVA)		(V)	(Amps)	(kW)	(kVA)		**(kW)**	(kVA)		(Tons)	**(Btu/Wh)**
07/17/01	80.0	67.0	60.2	57.2	0.326	1,200	95.0	75.6	1,133	117.4	**240.6**	12.18	2.678	2.93	0.914	120.0	4.58	0.502	0.550	0.914	**3.181**	3.480	**0.914**	3.09	**11.66**
07/17/01	80.0	67.1	59.9	57.0	0.296	1,161	95.0	75.3	1,125	116.0	**229.9**	12.00	2.611	2.76	0.947	114.7	4.65	0.484	0.533	0.908	**3.095**	3.291	**0.940**	3.09	**11.97**
07/17/01	80.0	66.7	59.2	56.3	0.273	1,116	95.0	75.5	1,118	114.4	**220.6**	12.11	2.577	2.67	0.965	110.1	4.68	0.464	0.516	0.900	**3.041**	3.186	**0.954**	3.04	**11.99**
07/17/01	80.0	66.9	58.7	56.0	0.243	1,053	95.0	76.0	1,108	114.6	**209.9**	12.49	2.560	2.62	0.977	104.7	4.71	0.438	0.493	0.889	**2.998**	3.114	**0.963**	3.01	**12.05**
07/17/01	80.0	67.2	58.3	55.7	0.214	989	95.0	76.5	1,098	113.8	**200.5**	12.99	2.558	2.60	0.982	100.0	4.70	0.413	0.470	0.879	**2.971**	3.074	**0.966**	2.98	**12.05**
07/17/01	80.0	67.0	57.2	54.7	0.182	911	95.0	76.3	1,065	113.7	**189.9**	13.59	2.542	2.58	0.985	94.8	4.64	0.381	0.440	0.866	**2.922**	3.021	**0.967**	2.91	**11.96**
07/17/01	80.0	67.0	56.3	53.9	0.155	840	95.0	76.3	1,070	114.8	**180.8**	14.27	2.542	2.58	0.985	90.2	4.55	0.351	0.411	0.855	**2.893**	2.991	**0.967**	2.85	**11.83**
07/18/01	80.0	67.0	60.0	57.3	0.322	1,200	95.1	75.8	1,087	113.3	**240.2**	12.17	2.684	2.92	0.919	120.0	4.59	0.503	0.551	0.914	**3.188**	3.473	**0.918**	3.10	**11.66**

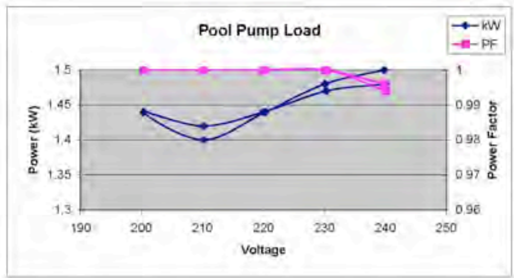




Note: This air-conditioning (A/C) unit was tested in PG&E's A/C performance test facility in San Ramon. Performance tests had just been completed on this unit as part of PG&E's customer energy efficiency programs, so it was left in place for this voltage reduction test. Although this unit had a standard residential size compressor, and a standard residential air handler/furnace unit, the condenser was not typical. This unit had a water-cooled condenser, where-as most residential units have an air-cooled condenser. Although the absolute values for the energy efficiency ratio (EER) may be different than typical units, the trend in performance due to voltage changes should be similiar since the compressor and furnace unit was typical. However, there are many different types of air conditioning units available, and further investigations would be needed to ensure that these results can be extended to other manufacturers and vintages. Also, A/C unit performance is very dependent on outside temperature, and evaporator coil inlet dry and wet bulb temperatures. These tests were performed holding these parameters constant at standard ARI (Air-conditioning and Refrigeration Institute) rating conditions. Results may vary at different operating conditions.

Loads
Pool Pump

Voltage	Current	kW	PF	kVA	
239.8	6.32	1.5	0.996	1.52	
230.1	6.25	1.48	1	1.44	1
220.3	6.37	1.44	1	1.40	1
210.1	6.61	1.4	1	1.39	1
200.3	6.89	1.44	1	1.38	1
210.1	6.54	1.42	1	1.37	1
220	6.33	1.44	1	1.39	1
230.3	6.25	1.47	1	1.44	1
240.1	6.32	1.48	0.994	1.52	



Note: This test was performed on a typical household pool pump at PG&E's San Ramon Test Facility. These preliminarey test results are for the specific pool pump that we have installed. While the pool pump is typical of a pool pumps used by residential customers, it by no means covers the full range of pool pumps in the typical residence. Further investigations need to be performed to ensure that these results can be extended to other manufacturers and vintages.

The graph above shows the low voltage performance of a pool pump, a typical 240-volt electrical motor. The minimum power demand and the maximum power factor again occur at 210 volts, not 240 volts.

The above two graphs above explain most of the 0.40% power reduction for each 1 volt drop in line voltage that was measured during peak demand times on distribution lines in 2001 (2% power reduction for a 5% voltage drop).

The California peak demand in 2004 was over 43,000 megawatts. A 5% voltage reduction would produce a 2% reduction in demand. This is a potential 860 megawatts. This much load reduction can be achieved by emergency voltage reduction (EVR) alone. No blackouts required. No customer knows the difference. **860 megawatts is the equivalent of one modern large power plant connected to the grid. In other words, the loss of a major power plant at peak demand time can be made up by instant small voltage reduction on utility distribution lines alone.**

- **Truck Stopping Device**. A simple and reliable truck stopping device (TSD) was designed which allows security personnel to safely stop big trucks that could be used by terrorists to attack critical gird infrastructure such as nuclear power plants. Remote controlled TSD units called CAPS (for Critical Area Protection System) were designed and extensively field tested on high-speed trucks at the Nevada Test Site and at the U.C. Lawrence Livermore National Laboratory. A variety of basic mechanically-activated TSD prototypes were field tested in order to find the most reliable and workable way to activate the brakes on a truck or trailer. This had to be done before a workable remote-controlled version (CAPS) could be designed and tested under realistic conditions. Prototypes were then field tested on a commercial fuel tanker truck for over 18 months with no problems of any sort. All versions of the TSD and CAPS are shown and described in Appendix II. Figure 2 below shows the “electronic fence” version of the CAPS transmitter stopping a big rig during the final demonstration on February 22, 2005, at the Livermore National Laboratory.

Figure 2 The electronic fence version of the remote controlled CAPS truck stopping device. The black cable on the ground in the left foreground is the linear antenna that radiates a signal perpendicular to the cable (across the roadway) for a distance of 30 to 100 feet. As the truck passes the cable, the CAPS receiver unit mounted on the truck-trailer is activated, causing the brakes on the trailer to be set. Skid marks can be seen in the right foreground where the truck was stopped in a previous test during the demonstration on February 22, 2005, at the UC Lawrence Livermore National Laboratory. Pat Lewis of the UC Lawrence Livermore National Laboratory is shown holding the small CAPS transmitter box that powers the linear antenna.

- **Vehicle Barrier.** A portable, movable, heavy vehicle crash barrier to protect grid infrastructure was designed and tested. This barrier is appropriate for protecting power plants, substations and transmission towers that are particularly vulnerable to truck bomber attack. It can be used where standard concrete barriers are not available or appropriate. This barrier was tested with high speed trucks at the Nevada Test Site. The barrier is made from sections of round steel pipe, 12 inches to 24 inches in diameter, 12 to 20 feet long. The pipe sections are strung together like a macaroni necklace on a 1 inch steel cable (wire rope). The ends of the cable are tied to the end sections of the barrier. A barrier of any length can be assembled quickly and/or moved by a few men who can roll pipe sections in place and connect them with simple tools. This barrier can be used anywhere that heavier concrete (K-rail) barriers are not available or appropriate. The pipe barrier is considerably less expensive than standard concrete barriers that require heavy-lift equipment to put in place. Used steel pipe is available almost everywhere. The pipe barrier is shown in Figure 3 below. It is fully described in Appendix III.

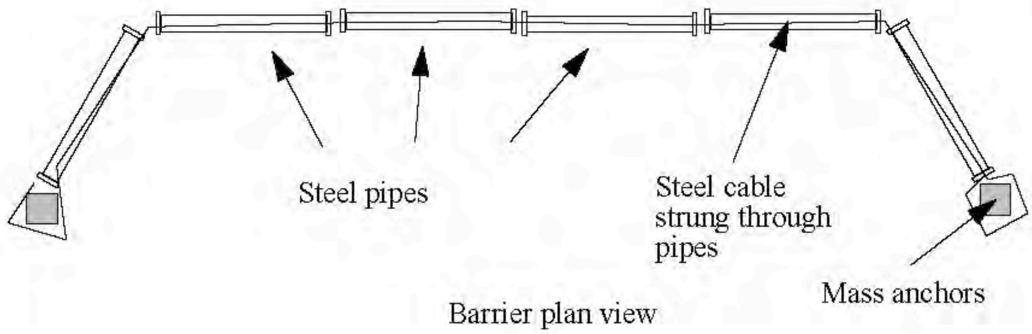


FIGURE 3 The Flexible pipe barrier. It is light in weight relative to concrete rail barriers and with the appropriate connection couplings, segments of the barrier can be moved by hand in a matter of minutes. The barrier provides some "give" when impacted by a speeding vehicle. The end masses provide the anchors for the cable system and react the inertial forces resulting from the vehicle impact. This barrier concept was tested in field experiments at the U.S. Department of Energy's Nevada Test Site (NTS) north of Las Vegas.

- **Appendices I, II, III, and IV at the end of this report show the final products of this research and testing work and the solutions to major threats to the electrical grid described above.**

- **The history of how the above research projects were planned and carried out and the project objectives are contained in the Introduction section of this report.**

Abstract

The work product delivered during this contract consists of solutions to some major threats to the stability and integrity of the electrical grid serving the state of California. This is one of the major objectives of the legislation that supplies the PIER research funds to the California Energy Commission. These solutions are: 1) A unique Load Reduction Switch (LRS) designed under this contract can create "soft blackouts" by cutting off all 240 volt power to a building while continuing to supply basic 120 volt power for essential and emergency services. If installed on even 10 percent of homes in a given area, the LRS can reduce power demand on the electrical grid enough to avoid rolling blackouts during many power emergencies. 2) An unanticipated discovery that was called Emergency Voltage Reduction (EVR). Laboratory low voltage tests on modern appliances and commercial motors during the LRS studies showed that voltages on utility distribution lines can safely be lowered a few volts during power emergencies to achieve large reductions in demand on a grid. 3) A unique truck stopping device (TSD) designed, tested, and perfected under this contract can prevent truck bomber attacks on critical power grid infrastructure such as nuclear power plants. The TSD technology can be installed on trucks to allow police to stop a hijacked speeding truck on the highways without great danger to police officers. Portable and remotely controlled TSD units called CAPS (for Critical Area Protection System) were developed under this contract. A CAPS unit can be attached to any truck entering a critical area so that security forces can stop the truck at any time. 4) An inexpensive, portable vehicle barrier designed and tested under this contract which stops speeding trucks attempting to breach a fixed security perimeter. Multiple prototypes of the physical solutions were built and extensively field tested under realistic conditions during this contract. The physical forms (working hardware) of three of these inventions are described and shown in the Appendices I, II, and III to this final report. The Governor of California requested that EVR be used during the 2001 California energy crisis, as described in Appendix IV. U.S. Patent number 6,670,728 entitled METHOD AND SYSTEM TO AUTOMATICALLY REDUCE GENERATED POWER was issued December 30, 2003 for the Load Reduction Switch. A patent application for the truck stopping technology has been filed. All patent rights to both of these inventions by Willard H. Wattenburg have been assigned to agencies of the State of California on the advice of the California Energy Commission.

1. Introduction

The Initial Contract

The initial work statement for contract 500-00-018 was proposed by the ENERGY COMMISSION staff and the Pacific Gas and Electric Company (PGE) in March 2001, in the midst of the California energy crisis of 2000-2001. PGE was asked by the ENERGY COMMISSION to test and evaluate a Load Reduction Switch (LRS) previously invented and demonstrated by W.H. Wattenburg at the U.C. Lawrence Livermore National Laboratory. The LRS could cut off all 240-volt appliances (such as air conditioners and water heaters) in a home or building while leaving the customer with enough 120-volt power for essential services. This brought about a typical 80% reduction in power demand from the average three-bedroom home during peak demand times. The LRS produced what was called a "soft blackout." Hence the title of the initial contract: "Advanced Switches for Soft Blackouts."

The LRS had the potential to reduce the load on the California electrical gird by amounts sufficient to avoid the rolling blackouts that were necessary during many power emergencies in 2000-2001. Power emergencies had occurred many times in the spring of 2001 because there was no more power available or power companies were asking exorbitant prices for a little extra power during a peak demand time. Severe power emergencies for the next several years were being predicted by "energy experts" who were quoted in the news media almost every day. Almost everyone predicted many more rolling blackouts in the summers of 2001 and 2002. The state was losing hundreds of millions of dollars a month because it had to purchase power for the major utilities.

Load Reduction Switch

There were two versions of the LRS that the ENERGY COMMISSION wanted tested. Both versions of the LRS produced what is called a "soft blackout" by cutting off all 240 volt loads within a building and leaving some 120 volt power for essential services.

Most utility customers are supplied with a 120-240 volt electrical service that consists of two 120 volt "legs" going to the customer's power panel. The voltages on the two alternating current 120-volt legs are out of phase by 180 degrees. 120-volt household appliances are serviced by one or the other of the two 120-volt legs. High energy appliances such as water heaters and air conditioners are connected to both of the 120 legs to give them 240 volt power. The mode 1 LRS works by simply cutting off one of the 120-volt legs to the building power panel. The mode 2 LRS does the same but then connects the "dead leg" to the remaining live 120 volt leg at the power panel.

In mode 2, the two 120-volt sides of the power panel are "in-phase." All 240-volt appliances are cut off completely because there is no net voltage across the two sides of the power panel (see the schematic for the mode 2 LRS in figure 5 of Appendix I). However, there was a known problem with the mode 2 LRS called the "branch circuit" problem that is described later. For this reason, mode 1 operation was considered the most desirable in the beginning. Unfortunately, the mode 1 LRS can produce low voltage (less than 120-volts) on appliances connected to the "dead leg." The consequences of this low voltage on appliances had to be investigated.

It was anticipated that Pacific Gas and Electric Co. (PGE) would be the main contractor and W.H. Wattenburg would be the principle investigator directing the experiments done at the PGE San Ramon Technology Center. Work began on April 2, 2001. **However, the ENERGY COMMISSION contract was not finalized until May 29, 2001, so that all work before that time as described herein was not billed to the state by either PGE or the principle investigator.**

Mode 1 Load Reduction Switch

Initially, it was believed that the mode 1 LRS would be the most desirable and useable version of the LRS. It simply disconnected one leg of the 120-240 volt power lines coming from the utility so that there was no 240 volt power delivered to the customer's power panel. The advantage of the mode 1 LRS is that it can be mounted on a distribution transformer to reduce the power demand of several houses at once. However, the mode 1 LRS, when activated, presents a potential problem. It produces variable low voltage on 120-volt household appliances connected to the "dead side" of the power panel while supplying full 120-volt power to all appliances connected to the "live side" of the power panel.

To test the mode 1 LRS, the contract specified that PGE construct an elaborate test set at its San Ramon Technology Center to measure the performance of all modern appliances under low voltages down to zero voltage. The test set built by PGE included all the appliances of two modern three-bedroom homes plus a variety of commercial equipment and motors. Intensive testing began on April 30, 2005.

The essential low voltage testing for the mode 1 LRS evaluation was completed by May 20, 2005. The test results showed clearly that the mode 1 LRS created too many inconveniences and uncertainties for customers. When the mode 1 LRS was activated on the PGE test set, the 120-volt circuits on the "dead leg" of the house power panel experienced variable low voltage from 0 to 100 volts depending on how many 240-volt loads were switched on at the time.

For instance, whenever the 240-volt water heater thermostat switched on and connected the water heater resistive element across the two sides of the power panel (which would normally be 240 volts), any 120-volt loads connected to the "dead side" of the power panel would suddenly have some voltage because of the small current flowing through the water heater element. This erratic behavior of the 120-volt circuits connected to the "dead side" of the power panel precluded using the mode 1 LRS for the majority of utility customers. Hence, thereafter, all work was focused on the mode 2 LRS.

Mode 2 LRS

When activated, the mode 2 LRS disconnects one leg of the 120-240-volt power lines coming into the power meter servicing a building, just like the mode 1 LRS. But then, the mode 2 LRS connects the "dead leg" going to the building's power panel to the "live leg" so that both legs have the same in-phase 120-volt power. Hence, all 240 volt power in the building is cut off and all 240 appliances stop drawing any current or power. All 120-volt circuits in the building have in-phase 120-volt power coming from both sides of the power panel. This produces no low voltage on any 120-volt circuits, but it presents another problem. The problem is that the mode 2 LRS can produce an excessive current in the neutral line of any "branch circuit" in a building. The common neutral of a branch circuit can overheat and cause a fire. This problem with the mode 2 LRS did not seem to be solvable in the beginning (that is why the mode 1 LRS was tested first in hope that it could be used).

Many buildings contain what are called "branch circuits" which are two 120-volt circuits which share a common neutral wire (three-wire #12 with a ground is commonly used). The two circuits are connected to different 120-legs at the power panel with a common neutral. The current flowing in one of the 120-volt branch circuits is 180 degrees out of phase with the current flowing in the other 120-volt circuit. Hence, the return currents flowing in the common neutral cancel each other rather than add to each other. But when mode 2 LRS operation connects the two 120-volt legs together at the power panel, the return currents flowing in a branch circuit neutral are in-phase and add together. This means that the current in the common neutral of a branch circuit can greatly exceed safe levels. Even though the current in each of the two branch circuits does not exceed the circuit breaker limit at the power panel, the common neutral wire can overheat and cause a fire. This problem had to be solved before the mode 2 LRS could ever be installed in the field.

Research Foundation, California State University, Chico, Becomes Prime Contractor

Throughout April 2001, it was intended that PGE would be the prime contractor for all the Load Reduction Switch work while the ENERGY COMMISSION staff was working on the contract. However. PGE filed for bankruptcy before the contract could be finalized. The ENERGY COMMISSION was not allowed to give a contract to PGE as the prime contractor thereafter. The Research Foundation, California State University, Chico, became the main contractor to the ENERGY COMMISSION on May 29, 2001. PGE was listed as a subcontractor to the Research Foundation. (The ENERGY COMMISSION paid for none of the testing work done before May 29, 2001.) PGE left the project in late July 2001. After that, all work focused on finding a solution to the branch circuit problem with the mode 2 LRS.

Solution of Mode 2 LRS Branch Circuit Problem

In late July 2001, W.H. Wattenburg developed a design of the mode 2 LRS that limits the current in one of the 120-volt legs to 10 amps. This limits the in-phase current flowing in the common neutral of any branch circuit to a safe level (when the branch circuit power panel circuit breakers meet code).

Over the next six months, several mode 2 LRS prototypes were built and tested in a new laboratory opened up by the Research Foundation, CSU Chico. These were meter-based designs that could be inserted beneath any standard power meter. A subcontractor, Keyspan Company of New York was hired to build production units of the latest prototype mode 2 LRS. The production version of the meter-based mode 2 LRS is shown in Appendix I, figures 1 and 2.

U.S. Patent # 6,670,728 covering both the mode 1 and mode 2 LRS was issued on December 30, 2003. All rights to this patent were assigned by the inventor, W.H. Wattenburg, to the Research Foundation, CSU Chico. As such, the state of California owns all the patent rights. (There was no obligation for Wattenburg to assign the patent rights to anyone because he had filed the original provisional patent at his own expense before doing any work on this contract with the ENERGY COMMISSION. That conclusion was made by ENERGY COMMISSION legal staff before the contract was awarded on May 29, 2001.)

In December 2001, ENERGY COMMISSION Commissioner Rosenfeld concluded that continuing major effort on the Load Reduction Switch was no longer justified. A pre-production version of the mode 2 LRS was on the shelf. The energy crisis in California had passed. It did not appear that installation of the LRS on a large number of homes would be necessary for the summer of 2002. In addition, Commissioner Rosenfeld concluded that significant progress was being made in the design of "smart power meters" that could accomplish the load reduction function of the LRS by directing the shutdown of household appliances during power emergencies.

It was decided that the only additional work on the LRS should be some basic residential tests to verify the switching reliability of the mode 2 LRS. This test would check only that the LRS would properly cut off 240 volt power when commanded to do so and that it would properly restore 240 volt power when commanded to do so or after a specified period of time had passed. This simple test was carried out over the next year while the principle investigator moved on to new “Grid Protection” tasks specified in changes to the contract work statement in January 2002.

An Unanticipated Discovery – Emergency Voltage Reduction to Reduce the Load on Electrical Grids.

During the mode 1 LRS investigation in April and May 2001, the extensive testing of most common household appliances and electrical commercial equipment showed a very surprising pattern: **All of the equipment tested performed very well at voltages as low as 100 volts (200 volts for 240–volt appliances). In fact, all of the household appliances and most of the commercial equipment (motors in particular) performed more efficiently in the range of 100 to 110 volts than at the standard 120 volts (equivalent 200 to 220 volts for 240-volt equipment). We measured significant power reductions when appliances were operated at lower voltages. (See the low voltage test data in Appendix IV)**

This presented a very interesting possibility: maybe the voltages on utility distribution lines could be lowered to reduce power demand on the grid during power emergencies? We could avoid rolling blackouts if distribution line voltages could be lowered a few volts quickly enough to reduce demand on the gird by as much as what was being accomplished with rolling blackouts? Here might be a way to accomplish the objective of the Load Reduction Switch without having to install any new hardware on hundreds of thousands or millions of homes and buildings.

This voltage reduction approach was soon called Emergency Voltage Reduction (EVR). EVR would only be done for a few hours at most during any power emergency. Voltages would be reduced only on local distribution lines, not at the power plant and transmission line level. (Conservation voltage reduction - CVR - has long been used by some utilities to reduce power demand and lower costs. CVR is usually a pre-planned operation that is not executed on an emergency basis. It is usually continued for a longer period of time, several days or more.)

The principal investigator reported the results of the low voltage testing and the possibility of using EVR to ENERGY COMMISSION Commissioner Arthur Rosenfeld on Tuesday, May 22, 2001. **We agreed that if EVR could be done, we would not have to install LRS units on hundreds of thousands of homes and businesses to achieve several hundred megawatts of power reduction to avoid most rolling blackouts during power emergencies.** This suggestion would seem to defeat the initial purpose of our research on the Load Reduction Switch. But such discoveries are what one hopes to find in a research project. Pursuing EVR was completely consistent with the contract objective of finding a way to avoid rolling blackouts during power emergencies.

There were no meaningful field tests on EVR that could be done in our laboratory in San Ramon. We continued with our contract specified work designing the mode 2 meter-based LRS during June 2001. We had a prototype design to test using some special high-current switches delivered by General Electric Co. The principal investigator suggested to ENERGY COMMISSION Commissioner Rosenfeld that he should contact the utilities to see if any of them would lower the voltage on one of their distribution lines to evaluate the EVR idea.

Large Utility tests EVR on its distribution lines:

ENERGY COMMISSION Commissioner Dr. Arthur Rosenfeld asked the Southern California Edison (SCE) to do an EVR test on a major distribution line. SCE has automated voltage adjustment equipment in its substations. They could do the test very easily and quickly at any time. They were rightfully worried that lowering the voltage would result in customer complaints or damage to customer equipment.

Nevertheless, SCE did the test on a hot afternoon in early-June 2001. They lowered the voltage 5% on a major distribution line serving over a hundred thousand homes and businesses of all types in Los Angeles. They kept the line voltage down for the rest of the afternoon. **The SCE engineers measured an immediate 2% reduction in power demand with a 5% reduction in voltage at peak demand time -- just as predicted from the laboratory low voltage data taken during the Load Reduction Switch study in May 2001. There were no complaints of any sort from SCE customers.**

These voltage reduction tests by SCE confirmed our former laboratory estimates that the power reduction would be 40% of the percentage of voltage reduction in the range 120 volts down to 114 volts. This means that a mere 2 ½ % voltage reduction down to, say, 117 volts from 120 volts can produce a power demand reduction of 1% on the grid. But 1% of 40,000 megawatts demand statewide during peak demand times is 400 megawatts. Most rolling blackouts during 2000-2001 ordered by the ISO reduced grid demand by less than 300 megawatts. Hence, it was clear that EVR could be used to prevent many rolling blackouts in the future.

Governor Requests California Public Utilities Commission to Allow EVR During Power Emergencies:

In mid-June 2001, ENERGY COMMISSION Commissioner Rosenfeld told the governor's office about the experiments done by the ENERGY COMMISSION on the Load Reduction Switch project (this contract) and SCE (on their own). He told the governor's staff that lowering the voltage by just 2 ½ % during power emergencies, from average 120 volts to no less than 117 volts, could possibly save enough energy to avoid the frequent rolling blackouts that were predicted by almost all "energy experts" for the coming summer months. The governor's office asked Commissioner Rosenfeld to arrange meetings with the utilities to see if they were willing to use EVR instead of rolling blackouts to reduce demand on the gird during future power emergencies.

There were a series of conference calls over the next two weeks between the governor's office, utility representatives, ENERGY COMMISSION Commissioner Rosenfeld, and W.H. Wattenburg (see June 16, 2001, memos in Attachment 1 in Attachment IV). In the last conference call on June 16, 2001, representatives from SCE, PG&E, and SDG&E agreed that they could reduce voltages and reduce power demand on the grid by 300 megawatts at least during power emergencies in the coming summer of 2001. PG&E, SCE, and SDE&D each pledged a certain amount of power reduction through EVR.

On July 3, 2001, the governor's office set up a statewide conference call to the media to announce that the governor was asking the California Public Utilities Commission to enact a regulation that would allow the governor to call for EVR during power emergencies to reduce demand on the grid and avoid rolling blackouts.

It was never necessary for the governor to request the use of EVR by the utilities. The California energy crisis came to a end four days later on July 7, 2001. That was the last day that there was any shortage of power at reasonable prices during peak demand times in California for the rest of the year.

In October 2001, the utilities opposed the governor's request before the CPUC for a regulation that would require the use of EVR during power emergencies. These were the same utilities that had agreed in June 2001 that EVR could be used during power emergencies.

EVR was initially proposed on the basis of test data from the PGE laboratory. In mid-July 2001, PGE stopped all testing work at their San Ramon Technology Center. Then in September 2001 PGE executives announced that they would do no more work on the Load Reduction Switch project. The laboratory was locked and the entire test set was dismantled. PGE refused to release any of the low voltage test data that had been collected during this project in their laboratory. However, the principal investigator had copies of all data collected during the experiments that he designed and helped carry out.

PG&E later announced that they would not complete their subcontract obligations under Contract 500-00-018 and that they would not submit a bill for any work done. Hence, they were not obligated to release officially any of the test data that had been recorded at their San Ramon Technology Center.

During hearings before the California Public Utilities Commission (CPUC) in October 2001, PGE representatives opposed the EVR regulation requested by the governor's office and supported by the ENERGY COMMISSION. They gave sworn testimony at the California Public Utilities Commission (CPUC) hearings claiming that the extensive low voltage test data recorded by their own engineers and W.H. Wattenburg in their San Ramon Technology Center "had not been peer reviewed or published and therefore it was not reliable" (CPUC Rule Making 00-10-002, October 5, 2001).

Appendix IV describes the full history and justification of the EVR proposal to the governor's office and many other events that transpired during the planning for EVR in 2001.

Truck Stopping Technology

A week after the terrorist attack on the World Trade Center on September 11, 2001, W.H. Wattenburg was asked to join a governor's anti-terrorism task force organized by the California Highway Patrol. The Governor's office asked the Executive Director of the ENERGY COMMISSION to participate in this task force because utility infrastructure and nuclear power plants were considered prime targets for terrorists. The task force ordered by the governor's office was charged with assessing the major infrastructure targets that terrorists might attack. It was concluded that truck bombers were the main threat and that fuel tanker trucks were the most dangerous. The Commissioner of the CHP made a request for any possible solutions to stopping big trucks that have been hijacked by terrorists. At that time there was no safe and effective way for police to stop a speeding big rig on the highways (see background in Appendix II).

In early October 2001, W.H. Wattenburg developed a simple mechanical means for police officers to safely stop trucks speeding on the highways. He built a truck stopping device (TSD) that mounts on the rear bumper of any truck or trailer. The (TSD) allows a police patrol car to set the brakes on the truck or trailer by simply lightly impacting (bumping) the rear bumper of the truck or trailer. This truck stopping device is the equivalent of a brake pedal mounted on the rear of the vehicle so that police can apply the brakes on the truck in manner that the driver in the cab can not overcome. It was tested on a truck in Greenville, California. W.H. Wattenburg filed a patent application on this technology in October 2001 at his own expense.

The truck stopping device (TSD) was demonstrated to the CHP at their Sacramento test track in late October 2001. The CHP and the governor's office asked that the TSD be developed for application on fuel tanker trucks as soon as possible. The governor's office contacted the Executive Director of the ENERGY COMMISSION and requested that the ENERGY COMMISSION work on the TSD project in a task force with the CHP. It was agreed that the work statement of contract 500-00-018 should be changed to authorize work on the truck stopping device (TSD) with the CHP. This work was authorized under the title "Grid Protection" because, clearly, major grid infrastructure such as nuclear power plants and transmission towers are prime targets for terrorist attack. No additional funding was added to the contract for the future grid protection work. The funds remaining in the contract that would not be used for further development of the Load Reduction Switch were considered sufficient to cover the new tasks to develop the TSD technology.

The governor's office also requested that the University of California Lawrence Livermore National Laboratory (LLNL) assist in the TSD testing and development project. Both the CHP and LLNL agreed to support the truck stopping experiments and field testing over the next year. Each agency more than matched the funding by the ENERGY COMMISSION over the next three years under contract 500-00-018.

Over the next three years, several different prototype truck stopping (TSD) units were designed and extensively field tested by the joint venture. Much of the testing was done at the U.S, Department of Energy Nevada Test Site using 80,000 lb. eighteen-wheeler trucks operated at high speed. The CHP sent its uniformed officers and patrol cars to do the chase and stop exercises. The best TSD design was installed on a commercial fuel tanker truck in April 2003. It has worked without failure on this commercial over-the-road truck for the last two years.

The principal investigator under this contract concentrated on designing a portable, remotely controlled version of the TSD called CAPS (for Critical Area Protection System). However, it was necessary to participate in the testing and improvement of the various prototypes of the basic mechanical TSD to achieve a reliable design that could be activated by remote control. Eventually, an inexpensive and very reliable TSD, called the spiral ratchet cartridge, was developed (see Appendix II). The spiral ratchet TSD can be manufactured for less than $50 per unit, and the entire installation on a truck or trailer can be done for less than $250. The spiral ratchet TSD connects to the main air brake control valve on a truck or trailer and activates the service brakes, not just the parking brakes on the truck or trailer as done by previous TSD prototypes. A prototype remote-controlled CAPS unit was soon built and tested.

CAPS is a portable unit the size of a shoe box (see Appendix II). It can be attached to the air lines between a truck and its trailer in less than a minute by security personnel at any critical facility as the truck enters the facility. The CAPS is removed from the truck as it leaves the facility. The portable CAPS can then be used on the next truck to enter the facility. Inside the CAPS enclosure is a combination of air valves that can be activated by coded radio signals. These air valves activate the service brakes on the trailer when commanded to do so.

CAPS can operate in several different modes as shown in Appendix II. In mode 1 operation, the movement of a truck is under the control of security personnel who can stop the truck anytime by punching a button on a hand-held transmitter. In mode 2 operation, the truck is stopped anytime it approaches a forbidden area that is marked off by a linear antenna that is constantly radiating a stop signal. Mode 2 operation is often called "electronic fencing." There is a mode 3 operation in which the CAPS must periodically receive coded radio transmissions. Otherwise, the CAPS is activated and the truck is stopped. The mode 3 "negative control" operation can be combined with either mode 1 and mode 2 operations. Any attempt to remove the CAPS enclosure from a truck or cut the air line connections to the CAPS results in the parking (spring) brakes on the truck being activated so the truck can not be moved. The mode 3 negative control operation is the best defense against terrorists who might attempt to block radio signals from being received by the CAPS.

All contract funds for the principal investigator were exhausted on December 15, 2004. The principal investigator and others at the Livermore Laboratory continued to work for the next two months to complete the latest electronics and plan the final field testing of the remotely operated version of the CAPS truck stopping device for protecting critical areas such as nuclear power plants. The CAPS was demonstrated to state and government officials and the national media at the Lawrence Livermore National Laboratory on February 22, 2005, as shown in Appendix II.

Live action video clips of all the TSD field tests done over the last three years on high speed trucks being stopped by police patrol cars and the remote controlled CAPS version can be seen at the bottom of the home page on the Livermore Laboratory website at:

www-eng.llnl.gov\tsd\tsd.html

(Be sure to type the www "dash" eng….. as shown in the URL above. If you swipe the URL above and then paste it into your browser window, some browsers will replace the www "dash" eng…. with www "dot" eng…. That will not work)

Patent on Truck Stopping Technology

A patent application covering all forms of the truck stopping devices described above was filed by the inventor, W.H. Wattenburg, at his own expense in November 2001, several months before work began on this technology under ENERGY COMMISSION contract 500-00-018. However, all patent rights have been assigned to the University of California Lawrence Livermore National Laboratory. The Livermore Lab is negotiating the final form of the patent to be issued at this writing. Hence, the state of California has been given the patent rights for the truck stopping technology and all improvements thereof that have resulted from the work described above.

Vehicle Barrier for Infrastructure Protection

The objective of this task in contract 500-00-018 was to design and test an inexpensive, but effective vehicle barrier that could be moved and set in place without the use of heavy equipment. This would allow the protection of grid infrastructure, such as exposed transmission towers and substations, that might be the target of terrorist truck bombers.

A number of possibilities exist for creating a physical barrier. However, there are often conflicts between limiting access for unauthorized vehicles and allowing access to authorized vehicles. The most widely used method of denying access is through the use of concrete rail barriers such as those found along highways (the most familiar being the “New Jersey” barrier denoting the state where it was originally designed and constructed). These massive concrete barriers can be very effective in stopping vehicles, however, they are massive and heavy, which requires the use of heavy equipment for placement. Once placed, the barrier can only be moved by bringing in heavy lifting equipment, and cannot be quickly changed to allow access status for authorized vehicles. In addition, these barriers may not be available in any location where a quick barrier is required.

The purpose of the testing and evaluation work specified in contract 500-00-018 was to investigate the utility of a new alternate vehicle barrier concept. The alternative barrier, originally proposed by W.H. Wattenburg, consists of sections of steel pipe through which a steel cable is strung and anchored on the ends as shown in Appendix III. It looks like a large macaroni necklace. This barrier can be constructed from materials that are readily available almost everywhere. barrier at high rates of speed.

The barrier tests consisted of guiding a remotely controlled one-ton truck into the pipe barrier at 40 mph. As shown in Appendix III, the tests were very successful. The truck flipped over after impact with the pipe barrier and landed a short distance away on its back. This result is very important compared to what happens with rigid barriers designed to stop a truck bomber at the barrier.

When a truck is stopped abruptly but stays on its wheels it can be used as a catapult platform for an explosive load that can be propelled a long distance toward a target beyond the barrier. Terrorists in the middle east have learned to use light trucks as catapult platforms for explosive packages that are launched in the air and travel some distance to a target beyond a rigid barrier that stops the truck. However, when the truck is raised up and flipped over after impact with the pipe barrier, such a catapult does not work to deliver an explosive package far beyond the stalled truck.

Full details of the tests conducted, pictures of the pipe barrier, the test vehicle, the test area, and the test results are shown in **Appendix III**

2. Project Approach

For each of the main tasks completed in this contract, the principal investigator designed prototype hardware solutions. A group of scientists from the Research Foundation (California State University, Chico), the University of California Lawrence Livermore National Laboratory, and uniformed officers from the California Highway Patrol tested those prototypes in the laboratory and in the field under realistic conditions to improve the prototypes and achieve the final hardware designs reported in Appendices I,II and III.

The unanticipated discovery of Emergency Voltage Reduction (EVR) as described above and in Appendix IV was recognized from analysis of the low voltage test data generated during the Load Reduction Switch task described in Appendix I. The ENERGY COMMISSION notified the governor's office. The governor's office requested several meetings with the major investor owned utilities to implement EVR. ENERGY COMMISSION officials and the principle investigator assisted the governor's office when they announced that the governor would ask the California Public Utilities Commission to require EVR to reduce demand on the grid during power emergencies.

For the vehicle barrier tests, two excess U.S. Department of Energy vehicles were obtained from the Nevada Test Site motorpool to serve as mock terrorist vehicles. The barrier was constructed with 24 inch steel pipe sections 20 feet long and one inch diameter steel cable. Since the objective of the experiment was to crash the vehicles into the barrier at high rates of speed, human drivers were out of the question and a remote control vehicle system was developed. The vehicle control system consisted of a radio commanded electronic control system mounted in the rear of the vehicle. The control system sent commands to a system of servos and linkages in the truck cabs which controlled steering, gas pedal, and brake. The control system package had to be assembled in a hardened enclosure to survive each crash so that it could be reused for the next truck and test.

3. Project Outcomes

1. A pre-manufacturing version of the mode 2 meter-based Load Reduction Switch (LRS) was designed. It was tested on two residences only because PG&E terminated its work on this project and closed its laboratory where the LRS work had been done from April to July 2001. The work product of this effort is described in Appendix I.

2. A remotely controlled truck stopping device called CAPS was built and tested in realistic security conditions. The work product of this effort is thoroughly described in Appendix II.

3. A portable vehicle barrier for infrastructure protection was designed and tested with high-speed trucks at the U.S. Department of Energy Nevada Test Site. The work product of this effort is thoroughly described in Appendix III.

4. An unanticipated discovery called Emergency Voltage Reduction (EVR) was recognized, verified, and recommended to the governor's office by the ENERGY COMMISSION as an alternative to rolling blackouts during the 2001 California energy crisis. On July 3, 2001, the Governor of the State of California requested that EVR be used immediately to avoid more blackouts during the summer of 2001. It was not used because the California energy crisis came to an end on July 7, 2001. This unanticipated discover and efforts to implement it are described in Appendix IV.

4. Conclusions and Recommendations

4.1. Load Reduction Switch.

Conclusions:

- Our laboratory and field testing showed that the mode 2 meter-based load reduction switch (LRS) with a 10 amp current limiter is the only practical form of the LRS that can be used safely in the field. This design solves the "branch circuit overloaded neutral" problem. It provides a minimum of 1200 watts of 120 volt power to the "low current side" of the power panel (limited to 10 amps) and normal 120 volt power to the "high current" side of the power panel.
- Actual testing showed that the mode 1 LRS (cut one leg only) presents major voltage variation problems that preclude it from being used (both the meter- based and transformer-based versions). The transformer-based mode 2 LRS is not safe because there is no way to set a safe yet adequate current limit to prevent the "branch circuit" problem in some home when several homes are being served by a common transformer.
- The mode 2 meter-based LRS (see Appendix I) can be used to make a substantial reduction (average 75%) in the electrical energy demand from the typical three bedroom home using air conditioning and other 240 volt loads on hot days. Our calculations show that a million LRS's installed on homes in California can reduce the demand on the electrical grid by up to 3000 megawatts during peak demand times. This is several times more than enough to have avoided any of the rolling blackouts during past power emergencies in California. This is equivalent to the power output of three 1000-megawatt power plants. The cost per meter-based LRS installed is less than $150. Hence, one million installed would cost 150 million dollars.
- The economy of the state of California lost at least a hundred million dollars of productivity every time rolling blackouts were called for several hours during power emergency days in 2000-2001. It would only take a few of these to exceed the cost of a million LRS's installed that could prevent forced blackouts.

- The missing technology that is necessary to use the LRS is a remote signaling system to activate the LRS installed on a home when necessary. A reliable, inexpensive remote signaling system does not exist as yet. One possibility is wide-area radio communication with special receivers installed in the LRS. Another candidate would be to use a pager receiver installed in each LRS. But the long-term cost for a million pager receivers is prohibitive. The ideal would be a reliable power line signally system that can use the utility power lines to send an on-off signal to any LRS installed on a customer's meter.

Recommendations:

- Analysis by the ENERGY COMMISSION staff and Commissioner Rosenfeld in December 2001 concluded that the new designs of "smart time-of-day meters" could do the job of the LRS by cutting off selected electrical loads at a location.

- No further work need be done to improve the design of the Load Reduction Switch (LRS) in the near future. Future PIER funding should concentrate on developing an inexpensive power line signally system that can be used to program either the LRS or smart meters of the future which can incorporate the circuitry to perform the function of the LRS to reduce power demand during power emergencies.

4.2. Truck Stopping Technology

Conclusions:

- A portable, remotely controlled truck stopping device (TSD) called CAPS has been designed and extensively field tested as shown in Appendix II. CAPS stands for Critical Area Protection System. A fully operational CAPS unit costs $800 in small quantities.
- CAPS can be used to control trucks entering and operating in any critical areas such as nuclear plants or around government buildings. A CAPS unit the size of a show box can be installed in about a minute on any truck by security personnel. The CAPS unit is removed when the truck leaves the critical area.
- CAPS allows trucks to be stopped on command by security personnel or by “electronic fencing” as shown in Appendix II.

Recommendations:

- There is no need for further work on the CAPS technology until such time as it requested by agencies that want modifications for their own applications. The present CAPS design is considered fully operational by one of the joint partners that preformed this work with the ENERGY COMMISSION, the UC Lawrence Livermore National Laboratory.
- Government agencies and power utilities that could use the CAPS technology should be notified as to what is available. The principle investigator made many requests to the PIER staff to do this. There is no evidence that this was done to date. The Contract Manager has CD video discs of all live field tests performed over the last two years on both the mechanical impact TSD and the CAPS form of the TSD. Copies of these field test CD’s can also be obtained from the Livermore National Laboratory. The test videos can be viewed on line on the Livermore Laboratory website:
  www-eng.llnl.gov\tsd\tsd.html

4.3 Portable Vehicle Barrier

Conclusions:

- An inexpensive but very effective vehicle barrier was constructed from sections of round steel pipe and field tested with high-speed trucks at the U.S. Department of Energy Nevada Test Site, as shown in Appendix III.
- This steel pipe barrier can be rolled into place by three or four men around any critical area such as a power plant or a particularly exposed transmission tower.
- This barrier is useful and appropriate where and when permanent concrete barriers are not possible or advisable.

Recommendations:

- No further research work is necessary on this barrier design. It has been adequately tested and documented for any agency or utility that may want to use it. The materials needed are readily available. Inexpensive used steel pipe is quite adequate. The U.S. military is considering using the pipe barrier to protect force installations in the field against suicide car bombers.

4.4 Emergency Voltage Reduction (EVR)

Conclusions:

- Emergency voltage reduction (EVR) is a very effective and painless alternative to rotating blackouts as a way to reduce the demand on an electrical grid that is suffering a demand overload. EVR can also be used to prevent a total grid collapse, such as happened during the massive northeast blackout on August 14, 2003. The official report of the investigation of the northeast blackout states that the blackout could have been prevented by immediate load reduction in the utility area that suffered a failed transmission line. However, the utility refused to cut service to their own customers without proof positive that the grid problem was being caused by their system. By the time they knew for sure it was their problem, it was too late to stop the collapse of the entire northeast grid. As an alternative to blackouts, the utility could have dropped the voltage on its distribution lines (EVR) to reduce the load without denying service to any customers. But none of the utilities in the northeast grid were prepared with a load reduction plan (blackout or EVR) that could have been executed in a few minutes time.

- The above conclusions are supported by the extensive test data shown in the Executive Summary above and in Appendix IV attached to this report. This test data collected as part of the Load Reduction Switch (LRS) work under this contract 500-00-018 shows very clearly that all home and commercial appliances operate very well, often better, at voltages as low a 105 volts, for reasons explained in Appendix IV. This means that distribution line voltage can be lowered by a few percent from the nominal 120 volts maintained by most utilities with no problem whatsoever.
- Tests conducted by SCE on fully loaded major distribution lines at peak demand times showed that power demand is lowered by 0.4% for each 1% reduction in line voltage from 120 volts down to 115 volts. Hence, lowering distribution line voltage by just 2 ½ % from 120 volts can reduce power demand on a grid by 1%. For instance, when grid demand is 40,000 megawatts, 2 ½% EVR can result in a load reduction of 400 megawatts. 400 megawatts is more than was saved by rolling blackouts during the power emergencies in California in 2000-2001.
- In June 2001, ENERGY COMMISSION Commissioner Rosenfeld recommended EVR to the governor's office to replace rolling blackouts as a means of load reduction during power emergencies. Commissioner Rosenfeld organized meetings with three large California utilities, PG&E, SCE, and SDG&E. The utilities committed to using EVR on their own distribution lines to achieve up to 300 megawatts of load reduction during future power emergencies in the summer of 2001. The Governor announced on July 3, 2001, that he wanted the California

Public Utilities Commission to order the major utilities in California to use EVR in the future rather than rolling blackouts.

Recommendations:

- The governor's office should immediately order the California "energy agencies" to formulate a system-wide emergency load reduction plan that can stop the "domino effect" of power plant disconnections that leads to rapid grid collapse. This plan must consider system-wide EVR as well as pre-planned local blackouts in each utility area in response to any serious grid overload. Ideally, this plan should include all utilities connected to the west coast grid. Any number of power plant or transmission line failures in the west coast grid could cause it to suffer the same consequences as the northeast gird in August 2004. Any blackout of the California grid will be disastrous to the California economy.

- All utilities in California should have an emergency voltage reduction (EVR) plan that can reduce power demand on the grid during stage 3 power emergencies that would otherwise require rotating blackouts.

- There is an obvious need for new building standards (efficiency standards) for air conditioners used in California, indeed the U.S. New air conditioners should have their peak efficiency centered between 220 volts and 230 volts. The modern air conditioning units tested in this study demonstrated peak efficiency at 210 volts. The power being wasted by present air conditioners operated at 240 volts far exceeds the savings possible from many of the PIER funded building standards projects and energy conservation programs.

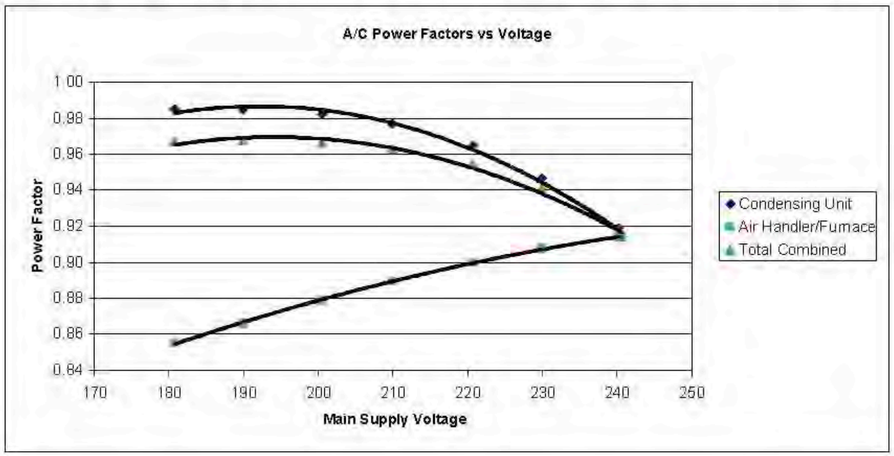
- The recommendations above are justified and supported by the most important low voltage test data from the PGE San Ramon Technology Center Load Reduction Switch project in 2001 that is summarized in the data tables and graphs below:

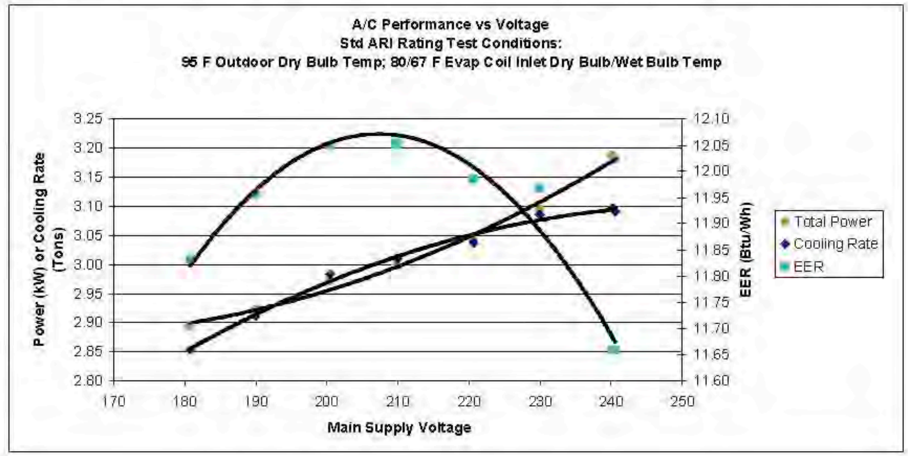
The combined data table and graph on the next page labeled "A/C Performance vs Voltage" show the overall performance of a typical modern air conditioner unit at voltages from 240 volts down to 180 volts. Note that the voltage at which the maximum EER (overall air conditioner performance factor, last column) occurs is 210 volts, not 240 volts. This means that a tremendous amount of energy is being wasted by operating millions of these air conditioners at the excessively high 240 volts. There is no question that a big reduction in load on a grid can be achieved simply by lowering distribution line voltages a few volts. Modern home air conditioners are a very big domestic load on the gird during most peak demand times.

Notice that the power savings by operating this air conditioning unit at 230 volts is 2.7%. It is 4.4% at 220 volts. And the power demand reduction is 5.8% at 210 volts.

Performance Test Results for A/C Unit versus voltage

Date	Evap Inlet Air Temp		Evap Outlet Air Temp		Evap Outlet Static Pressure	Evap Air Flow	Condenser Inlet Air Temp		Cond Air Flow	Compressor / Motor Shell Temp	Condensing Unit Power					Air Handler/Furnace Power					Combined Power			Performance	
	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb			Dry Bulb	Wet Bulb			Voltage	Current	Power		Power Factor	Voltage	Current	Power		Power Factor	**Power**	kVA	Power Factor	Cooling Rate	**EER**
	(ºF)	(ºF)	(ºF)	(ºF)	(IW)	(ACFM)	(ºF)	(ºF)	(ACFM)	(ºF)	**(V)**	(Amps)	(kW)	(kVA)		(V)	(Amps)	(kW)	(kVA)		**(kW)**	(kVA)		(Tons)	**(Btu/Wh)**
07/17/01	80.0	67.0	60.2	57.2	0.326	1,200	95.0	75.6	1,133	117.4	**240.6**	12.18	2.678	2.93	0.914	120.0	4.58	0.502	0.550	0.914	**3.181**	3.480	**0.914**	3.09	**11.66**
07/17/01	80.0	67.1	59.9	57.0	0.296	1,161	95.0	75.3	1,125	116.0	**229.9**	12.00	2.611	2.76	0.947	114.7	4.65	0.484	0.533	0.908	**3.095**	3.291	**0.940**	3.09	**11.97**
07/17/01	80.0	66.7	59.2	56.3	0.273	1,116	95.0	75.5	1,118	114.4	**220.6**	12.11	2.577	2.67	0.965	110.1	4.68	0.464	0.516	0.900	**3.041**	3.186	**0.954**	3.04	**11.99**
07/17/01	80.0	66.9	58.7	56.0	0.243	1,053	95.0	76.0	1,108	114.6	**209.9**	12.49	2.560	2.62	0.977	104.7	4.71	0.438	0.493	0.889	**2.998**	3.114	**0.963**	3.01	**12.05**
07/17/01	80.0	67.2	58.3	55.7	0.214	989	95.0	76.5	1,098	113.8	**200.5**	12.99	2.558	2.60	0.982	100.0	4.70	0.413	0.470	0.879	**2.971**	3.074	**0.966**	2.98	**12.05**
07/17/01	80.0	67.0	57.2	54.7	0.182	911	95.0	76.3	1,065	113.7	**189.9**	13.59	2.542	2.58	0.985	94.8	4.64	0.381	0.440	0.866	**2.922**	3.021	**0.967**	2.91	**11.96**
07/17/01	80.0	67.0	56.3	53.9	0.155	840	95.0	76.3	1,070	114.8	**180.8**	14.27	2.542	2.58	0.985	90.2	4.55	0.351	0.411	0.855	**2.893**	2.991	**0.967**	2.85	**11.83**
07/18/01	80.0	67.0	60.0	57.3	0.322	1,200	95.1	75.8	1,087	113.3	**240.2**	12.17	2.684	2.92	0.919	120.0	4.59	0.503	0.551	0.914	**3.188**	3.473	**0.918**	3.10	**11.66**

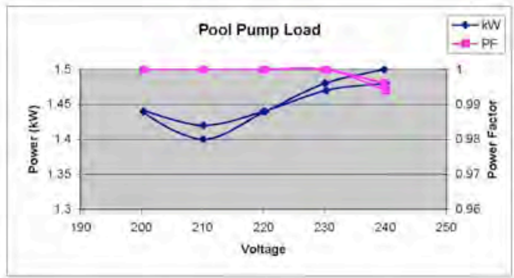




Note: This air-conditioning (A/C) unit was tested in PG&E's A/C performance test facility in San Ramon. Performance tests had just been completed on this unit as part of PG&E's customer energy efficiency programs, so it was left in place for this voltage reduction test. Although this unit had a standard residential size compressor, and a standard residential air handler/furnace unit, the condenser was not typical. This unit had a water-cooled condenser, where-as most residential units have an air-cooled condenser. Although the absolute values for the energy efficiency ratio (EER) may be different than typical units, the trend in performance due to voltage changes should be similiar since the compressor and furnace unit was typical. However, there are many different types of air conditioning units available, and further investigations would be needed to ensure that these results can be extended to other manufacturers and vintages. Also, A/C unit performance is very dependent on outside temperature, and evaporator coil inlet dry and wet bulb temperatures. These tests were performed holding these parameters constant at standard ARI (Air-conditioning and Refrigeration Institute) rating conditions. Results may vary at different operating conditions.

Loads
Pool Pump

Voltage	Current	kW	PF	kVA	
239.6	6.32	1.5	0.996	1.52	
230.1	6.25	1.48	1	1.44	1
220.3	6.37	1.44	1	1.40	1
210.1	6.61	1.4	1	1.39	1
200.3	6.89	1.44	1	1.36	1
210.1	6.54	1.42	1	1.37	1
220	6.33	1.44	1	1.39	1
230.3	6.25	1.47	1	1.44	1
240.1	6,32	1.48	0.994	1.52	



Note: This test was performed on a typical household pool pump at PG&E's San Ramon Test Facility. These preliminarey test results are for the specific pool pump that we have installed. While the pool pump is typical of a pool pumps used by residential customers, it by no means covers the full range of pool pumps in the typical residence. Further investigations need to be performed to ensure that these results can be extended to other manufacturers and vintages.

The graph above shows the low voltage performance of a pool pump, a typical 240-volt electrical motor. The minimum power demand and the maximum power factor again occur at 210 volts, not 240 volts.

The above two graphs above explain most of the 0.40% power reduction for each 1 volt drop in line voltage that was measured during peak demand times on distribution lines in 2001 (2% power reduction for a 5% voltage drop).

The California peak demand in 2004 was over 43,000 megawatts. A 5% voltage reduction would produce a 2% reduction in demand. This is a potential 860 megawatts. This much load reduction can be achieved by emergency voltage reduction (EVR) alone. No blackouts required. No customer knows the difference. **860 megawatts is the equivalent of one modern large power plant connected to the grid. In other words, the loss of a major power plant at peak demand time can be made up by instant small voltage reduction on utility distribution lines alone.**

The principle investigator believes that the EVR discovery and the plans to implement it during the California energy crisis of 2001 may well be the most valuable result of this contract work if it can be utilized to prevent major grid collapse in the future.

4.5. Recommendation on PIER Priorities

A 500 million dollar a year state agency with the title "California Energy Commission" should be addressing the highest priority of all: protecting the electrical energy supply for the state. The highest priority of all is to make sure that the electrical grid of California does not again suffer forced blackouts of the kind that occurred in 2000-2001 and that it does not collapse completely as happened in the northeast in August 2003.

The legislation that authorizes the PIER funds each year states that one main purpose of the PIER funds is to support research directed at safeguarding the energy supply of the state. However, it appears that the ENERGY COMMISSION has removed that objective as a major "focus" of its PIER programs. A standard attachment to all PIER contracts is Attachment A-2 . The "Preface" section of Attachment A-2 instructs the writers of final contract reports to include a paragraph in all reports that lists the program areas supported by PIER funds. Attachment A-2 now reads:

> The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.
>
> The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.
>
> PIER funding efforts are focused on the following six RD&D program areas:
>
> - Buildings End-Use Energy Efficiency
> - Industrial/Agricultural/Water End-Use Energy Efficiency
> - Renewable Energy
> - Environmentally-Preferred Advanced Generation
> - Energy-Related Environmental Research
> - Strategic Energy Research.
>
> For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.
>
> (end Pier Attachment A-2)

Notice that the PIER R&D program list in Attachment A-2 above does not specifically focus on safeguarding the electrical grid and energy supply for the state. Indeed, PIER supervisors suggested to the principal investigator in 2004 that designing or building solutions to immediate threats to the electrical grid was not appropriate for PIER funding. If this is true, when the next energy crisis or major blackout hits California, the California Energy Commission managers may again be scratching their heads without a clue as to what to do about it, as they were at the beginning of the 2000-2001 energy crisis.

The work preformed in this contract has shown that there are ways to protect the grid that are not now being used. There are probably even better ways to be discovered. The PIER program should be devoting at least a few percent of its 80 million dollars per year to Grid Protection work that can be used in the very near future to prevent grid blackouts or total grid collapse. The management of the California Energy Commission, the Legislature, or the governor's office should clarify the purpose of the PIER funds and the agency.

4.6. Total Cost of Contract 500-00-018 Work

The total cost to the California Energy Commission and the State of California of all work performed under this contract 500-00-018 over four years, April 2001 to March 2005, was $800,000. This is $200,000 per year, or about the same as the total cost to the state of one senior management state employee (with full benefits). The ENERGY COMMISSION was charged only for the services of one principal investigator and one engineering assistant at the Research Foundation, California State University, Chico. The ENERGY COMMISSION was not charged for any of the extensive technical work done by the principal investigator before May 29, 2001. The ENERGY COMMISSION did not pay for the patent applications filed for the Load Reduction Switch and the truck stopping technology. The principle investigator was not reimbursed for his patent application expenses. He was not paid for the patent rights which he voluntarily conveyed to state agencies.

Appendix I to Final Report

California Energy Commission

Contract 500-00-018

March 30, 2005

The Load Reduction Switch

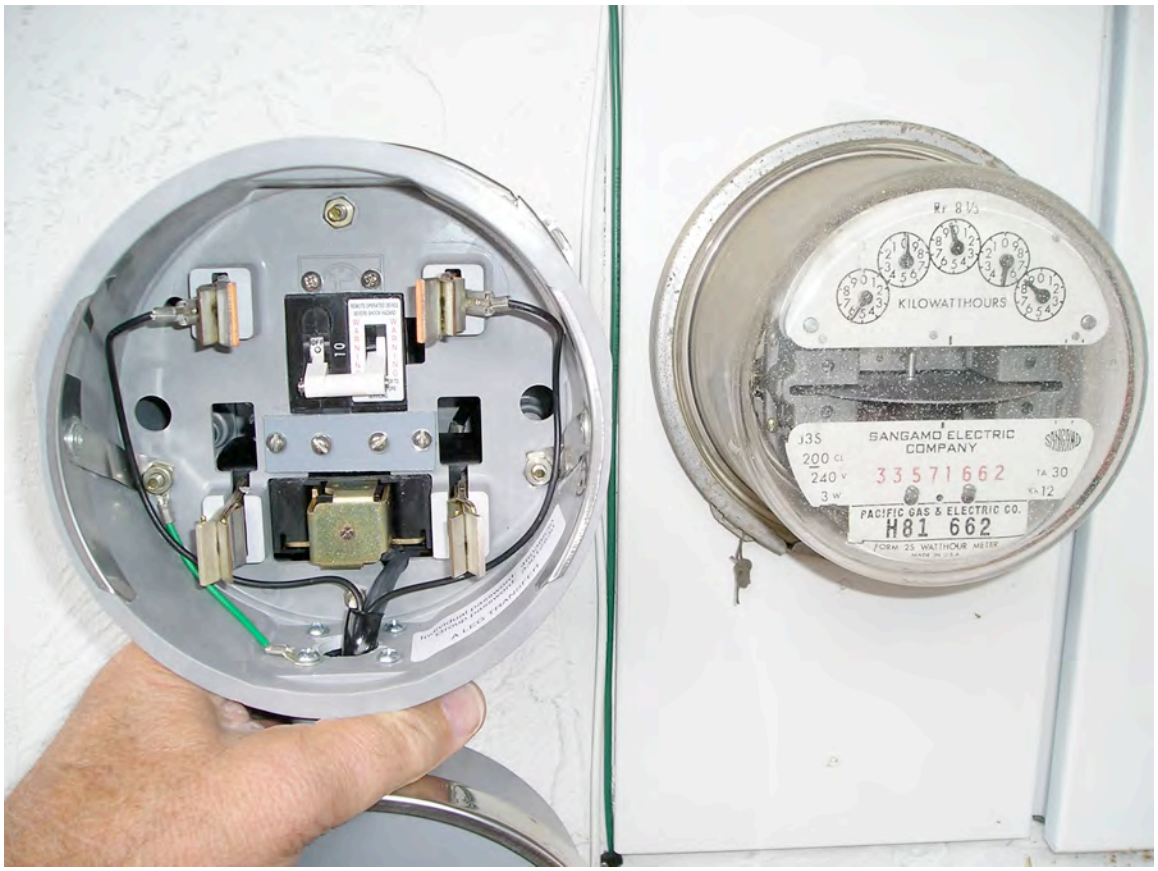


Figure 1: Front view of the Keyspan LRS prototype (left) being held by the author next to a standard power meter (right) for comparison. The LRS is a meter based insert 6 inches deep that plugs in between the meter and the meter base. The black item in the middle of the base unit with the number 10 is the 10 amp circuit breaker which limits the current flow to one side of the house power panel. The section of the LRS below the author's hand contains the control circuitry, such as a paging receiver or radio receiver, that switches the LRS on and off according to the specifications in Figure 3. This is a mode 2 LRS that switches both 120-volt legs at the power panel to in-phase 120-volt power thereby cutting all 240-volt power in the building serviced by the panel. The fully tested prototype and specifications for the Keyspan production unit shown above came the laboratory design and testing work under this contract during 2001.

Figure 2: Side view of the Keyspan prototype LRS unit (left) held next to a standard power meter (right). The meter base engaging plugs can be seen on the right side of the LRS shown.   Power meter maintenance personnel need no additional special technical training to install the LRS.

1.0 Specifications

ELECTRICAL:

Surge Withstand: Designed to ANSI C62.41

Switch Ratings:

Number: Two double pole

Type: BLP Series 36 200A latching

Nominal voltage: 240 VAC

Maximum continuous load: 200A, 50/60 Hz

Maximum inrush: 6000A, 6 cycles 0.7/0.8 PF lagging

Contact closure period: 1 or 2 second control signal (depending on options ordered)

Power Supply Protection:

Two 4,500A MOV's on the 240VAC side

Isolation transformer between the primary and secondary side of the power supply

MOV surge protector on the load side of the transformer.

Two 10A slow blow fuses on the line side of the transformer.

Current Limiting and Thermal Shutdown

MECHANICAL:

Enclosure: Ekstrom NEMA 3R

Mounting: 4 jaw meter base

Dimensions: 5 ¼" extension meter adapter

SAFETY INTERLOCKS:

Mechanical Interlock to prevent cross phase condition

OPTIONS:

Current Limiting Breaker: 10A motor operated magnetic/single pole

ENVIRONMENTAL:

Operating Temperature: -20 C to +70 C (-4F to +158 F)

Humidity Range: 0 to 95% (non-condensing)

COMMUNICATIONS:

900MHZ Commercial Paging

PACKAGING:

Paging receiver/power supply mounted below adapter

5

Figure 3: Specifications for the Keyspan prototype LRS shown in figures 1 and 2.

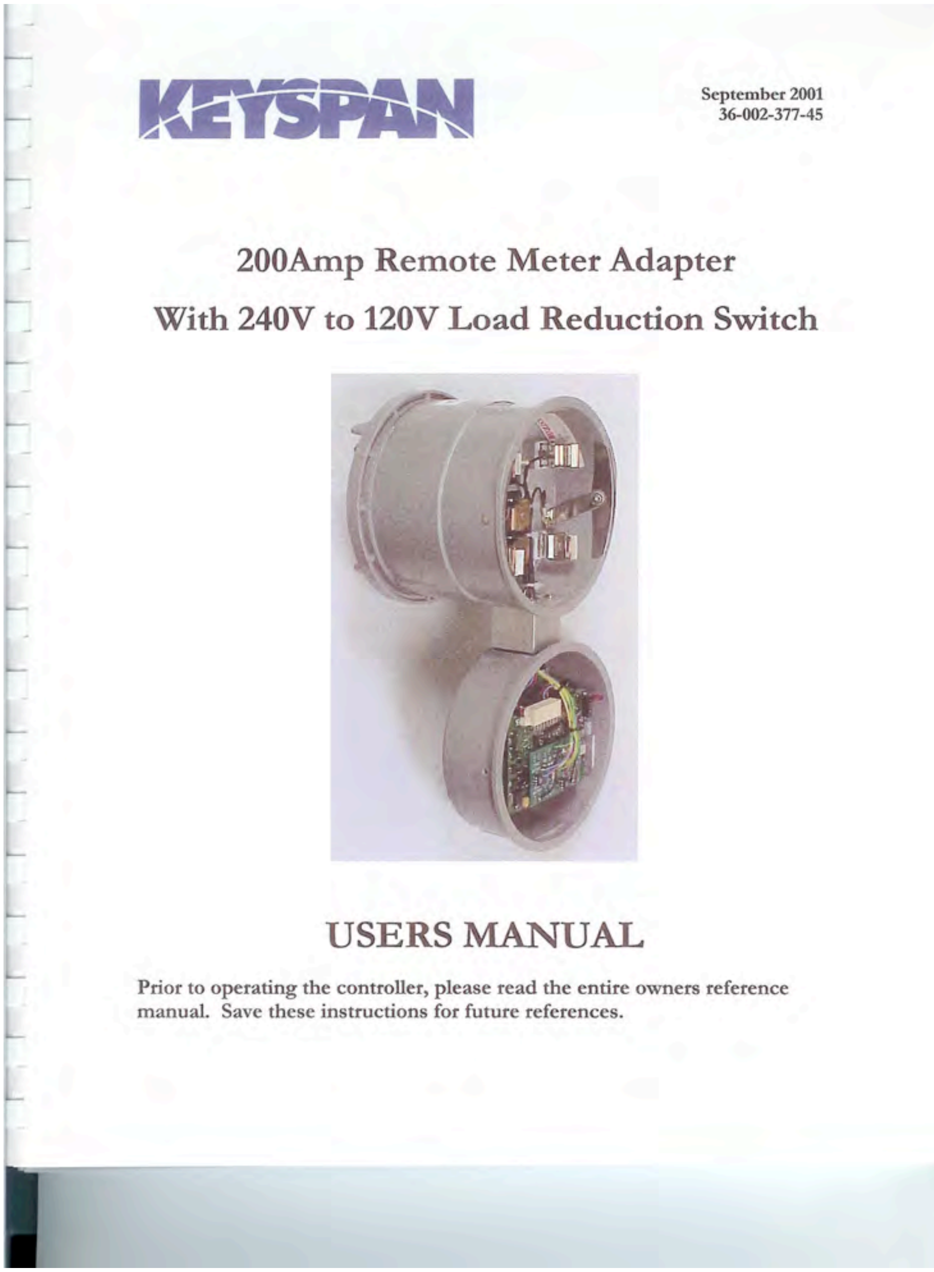
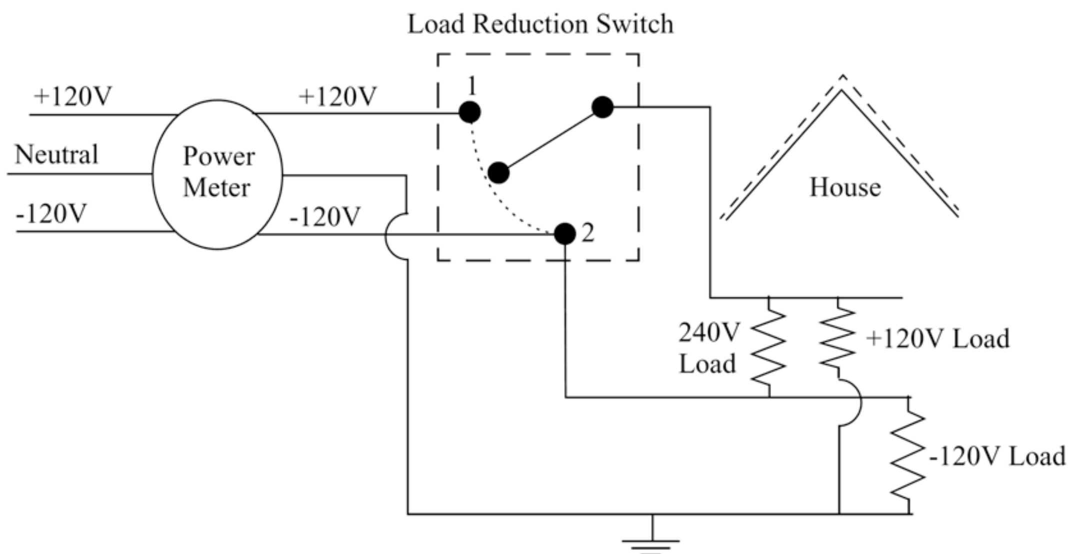


Figure 4: Title page of the owner's manual delivered for the prototype LRS built by Keyspan.

Figure 5: Below is a schematic showing where the mode 2 Load Reduction Switch is installed in the power lines leading to the house power panel. The LRS is mounted between the meter base and the standard power meter. When the LRS is activated by a timer relay or any other device that provides a contact closure, the internal switch in the LRS moves to position 2. This cuts off all 240 volt power by putting both 120 volt lines in phase with the -120 line as shown. The LRS automatically resets to the normally closed position 1 if it does not receive a reset signal after a programmed "reset time" such as one hour.

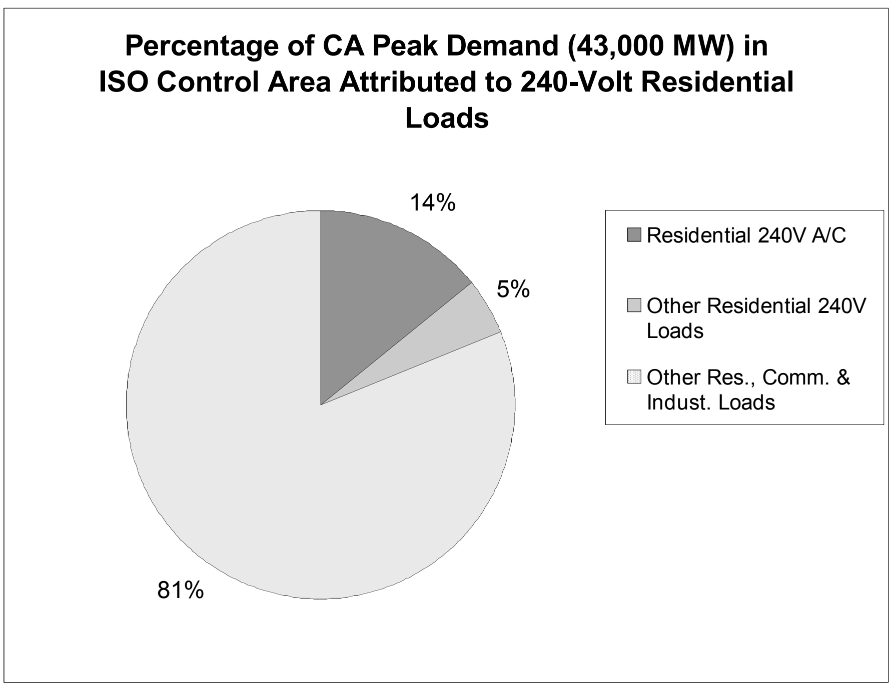


The Load Reduction Switch project began with the following report prepared by the staff of the California Energy Commission on April 2, 2001. This report was also sent to the governor's staff in charge of energy matters.

"Soft" Blackout Program Status
California Energy Commission

Background

Rolling blackouts are currently the response being taken during Stage 3 power emergencies. These blackouts are expensive, disruptive, and pose risks to public safety and health. Residential 240-volt load accounts for almost 20% of California's peak demand, or about 10,000 MW (see figure below).

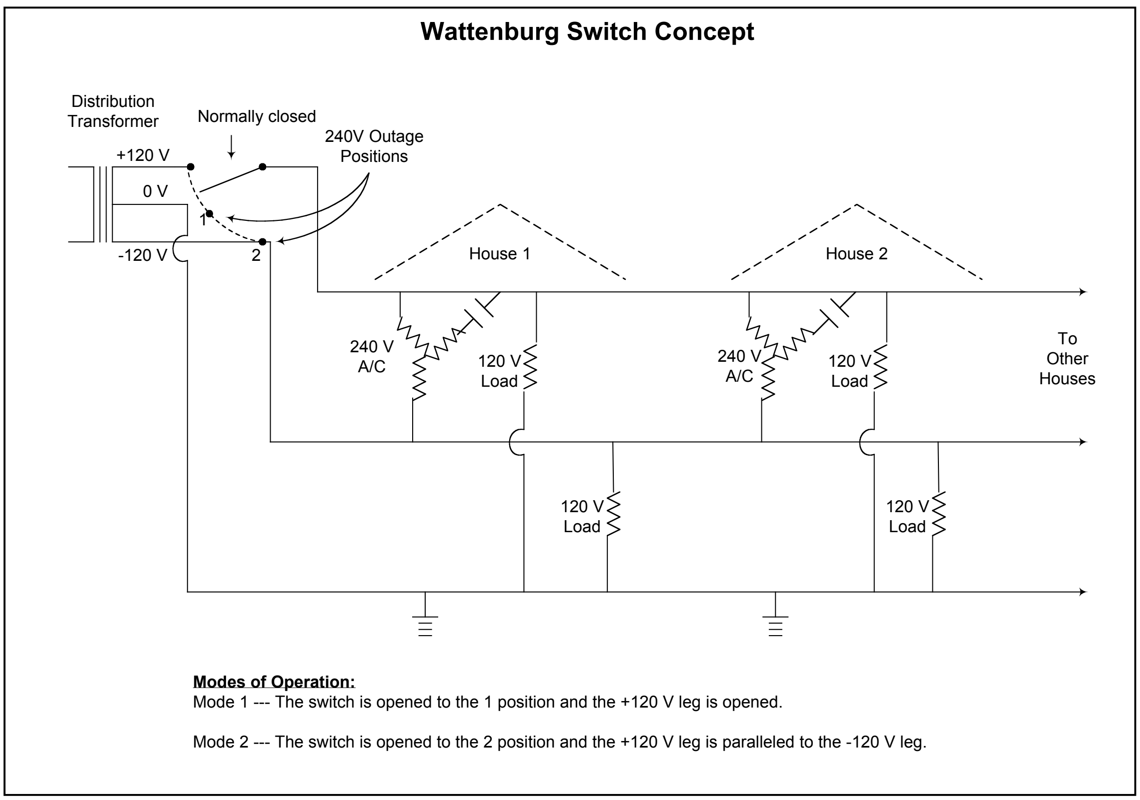


Development and implementation of control technologies for rolling "soft" blackouts, that is, blackouts affecting only residential 240-volt load, would alleviate many of the seriously negative aspects of total blackouts. In addition, by reducing peak demand, considerable savings could accrue for the cost of electricity purchases.

Wattenburg Switch Concept and Description

Bill Wattenburg has designed a switch that can be used to turn off only residential 240-volt load. The switch is installed on the utility system between the distribution transformer and the house(s) that it serves. It can be operated manually or remotely based on a radio or cellular phone signal, which can be sent from a central station in response to a request to reduce peak electrical use. The installed costs are estimated to be $600 per switch.

A schematic diagram of the Wattenburg Switch concept is shown in the figure below.



These devices would primarily be installed on residential transformers and not commercial or industrial services. A desirable feature of this invention is that during hot weather, for instance, sufficient load reduction can be achieved by cutting off large numbers of home air conditioners in such a way that factories and businesses are not affected. This is because most large places of employment such as factories and office buildings are not directly serviced by utility 240-volt step-down transformers. They have their own internal 240-volt step-down transformers that will not be affected by a system-wide load reduction signal sent out by the utility to the residential transformers containing the device. However, large businesses can still reduce loads as they do now by manual procedures. The important thing is that rolling blackouts do not need to be done that cut off all places of employment in order to cut off unessential or unused home appliances in the same region. Since the switch would be located in or near a transformer enclosure, another advantage of the switch would be the inability to physically disable the switch.

Issues

There are two broad issue areas we must address in planning further development and testing of this switch. First, there are a number of competing technologies that have already been commercialized. Comverge, Inc., for example, has made an independent proposal to the Department of Water Resources to install 250,000 devices to achieve load curtailment, with a portion of this being accomplished through temperature setback devices, over the course of their contract.

Comverge is also the supplier of the radio receiver and switch located at the A/C units for Southern California Edison's (SCE) air conditioning cycling program. Currently, SCE has 125,649 devices in residences (with coincident peak demand savings of 1.75 kW power per device) and 17,985 devices in commercial establishments (with coincident peak demand savings of 2.26 kW per device), for a theoretical total load savings of about 260 MW. However, SCE audits found that approximately 17% of the devices would not function as intended (2.4% control device failure, and 14.7% no-response due to control device disconnected/removed or A/C unit not operable). The one time installation cost for a residential unit is $153 with annual administration cost of $17 per year. The approximate cost to maintain the head-end control system is $50,000 per year. The costs for the radio broadcast equipment are part of the annual support for SCE's microwave and fiber network.

Cannon Technologies has a paging-based load control system with similar capabilities to those of Comverge. Cannon developed a similar set of proposal options for the Energy Commission earlier this year.

In addition, the California Public Utilities Commission issued draft decision (Rulemaking 98-07-037) on Load Control and Distributed Generation Initiatives. Within this ruling is the implementation of a pilot program to test the viability of a new approach to residential load control and demand-responsiveness through the use of internet technology and thermostats to affect air conditioning energy use. This program is designed to include approximately 5,000 residential and 5,000 small commercial customers in San Diego Gas & Electric service territory, representing an estimated 8 MW in peak demand reduction, to produce savings before the end of 2002. Sacramento Municipal Utilities District also has an active air conditioning cycling program involving approximately 50,000 units.

The second issue is to develop an understanding of how the switch will work with the existing control systems used by the operators to conduct rolling blackouts. The technical ability of the switch to soften blackouts through reducing or eliminating the need to black out traffic signals and household communications needs to be addressed. Some concerns are:

- There must be coordination between switch operation and transmission and distribution system controls.
- In disabling the 240-volt load, the neutral could be overloaded.
- Paralleling both 120-volt legs could result in transformer overheating.
- Opening one leg of a 240/120-volt system violates the National Electrical Code.
- Customer meter will not operate when one leg to the 240-volt source is switched open.
- The device may not withstand the expected operational and environmental conditions.
- The necessary communication infrastructure may not be available.
- The impact on appliances and equipment within the residence and possibly to other residences connected to the same transformer could be severe.

Status

The switch is still in the concept stage and no field-ready device suitable for utility installation exists. The Energy Commission is presently initiating a phased research program with Pacific Gas & Electric (PG&E) over the next several months to identify critical issues with the Wattenburg Switch.

The next steps are to expand the testing to measure the interaction of the switch with typical residential loads; test production devices (when available) to determine their suitability for utility application; and evaluate the operational implications of using this switch.

We will also evaluate the operational characteristics of this device in applications that help avoid Stage 3 blackouts with other, similar commercially available products. This will be done, in part, by convening an advisory committee for the test program and an air conditioning cycling evaluation group.

Specifically, there are six primary objectives of the planned research with PG&E. The objectives and anticipated completion dates are:

1. Determine the impacts and consequences of opening one hot leg of 240-volt electric service on the appliances and equipment that are normally in a residence. This work will be completed by June 2001.

2. Determine the impacts and consequences of connecting both legs of a standard residential service to one side of the transformer, effectively reducing residential service to 120-volts on appliances and equipment that are normally in a residence. This work will also be completed by June 2001.

3. Determine the impacts and consequences of doing the above to a house while it is operating normally. This will be completed by September 2001.

4. Determine the impacts and consequences of doing the above to a group of homes served by one distribution transformer. This will be completed by November 2001.

5. Determine the utility infrastructure and interface requirements for operation of the switch and other technologies that work to "soften" Stage 3 rolling blackouts for residential, commercial and industrial customers. Evaluate the effectiveness of operation during blackout conditions and as load management. This work will be completed by November 2001.

6. Determine the impact and corrective actions necessary as a result of no metering during a soft blackout. This will completed by November 2001.

7. Compare Wattenburg Switch with existing alternatives. This will be completed by December 2001.

Summary

The Wattenburg Switch is an innovation that has the potential to soften blackouts and to considerably alleviate peak demand beginning in 2002. However, research must be performed to confirm the potential applications and to address concerns raised by others. The Energy Commission must also assess the Wattenburg Switch technology and its relative advantages as compared to similar technologies, considering issues such as technical and cost effectiveness, availability and ease of implementation. Following the evaluation of this information, the Energy Commission will determine whether or not to make a recommendation for initiating a $5 - $10 million pilot program of the Wattenburg Switch beginning in January 2002 that can provide benefits by the summer of 2002.

Appendix II to Final Report
California Energy Commission
Contract 500-00-018
March 30, 2005

The Truck-Stopping Technology Developed by the California Energy Commission, California Highway Patrol, UC Lawrence Livermore National Laboratory

The Evolution of the Critical Area Protection System (CAPS)

Figure 1: The electronic fence version of the remote controlled CAPS truck stopping device. The black cable on the ground in the left foreground is the linear antenna (electronic fence) that radiates a signal perpendicular to the cable (across the roadway) for a distance of 30 to 100 feet. As the truck passes the cable, the CAPS receiving unit mounted on the truck-trailer is activated, causing the brakes on the trailer to be set. Skid marks can be seen in the right foreground where the truck was stopped in previous tests during the demonstration on February 22, 2005, at the UC Lawrence Livermore National Laboratory. Pat Lewis of the U.C. Lawrence Livermore National Laboratory is shown holding the small CAPS transmitter box that powers the linear antenna.

Figure 2:

Test of the mechanical rear impact truck stopping device (TSD) and the first remote controlled versions called CAPS at the U.S. Department of Energy Nevada Test Site. California Highway Patrol (CHP) personnel worked with the California Energy Commission and Lawrence Livermore National Laboratory teams to test all TSD prototypes on high-speed trucks from 2002 to 2004. Here a CHP patrol car is bumping the rear bumper of the trailer as the truck-trailer combination travels at 50 mph and swerves as violently as it can without overturning. Lightly bumping the rear of the big truck or trailer proved to be a very easy and very safe procedure for the CHP officers because a heavy truck can not change speed or direction very rapidly compared to the maneuverability of a patrol car (any driver who has ever followed cars on the freeway at high speed knows how easy it is to move closer to a vehicle ahead). The extensive field tests showed that the faster the truck is moving, the easier it is for a patrol car to bump the rear of the truck with no damage whatsoever to the patrol car or danger to the driver. Even when the brakes lock up on the truck or trailer, the truck decelerates far more slowly compared to the stopping rate of a lighter car.

The picture above shows the remote control receiving and recording equipment mounted on a shelf high above the rear bumper of the trailer. The second CHP patrol car nearest to the viewer is a chase car that is filming close-ups of the truck stopping action. All tests were video taped. These are available on CD and posted on the Livermore Lab website.

Over twenty live field tests with high speed trucks (twenty four days in the field and at test sites with crews over two years) showed that chase car drivers need no special training to execute the maneuver without danger to the chase car driver or any damage to the patrol car whatsoever. The high bumpers on the front of most police patrol cars are ideal for contacting the standard under-ride bumpers on the rear of trucks.

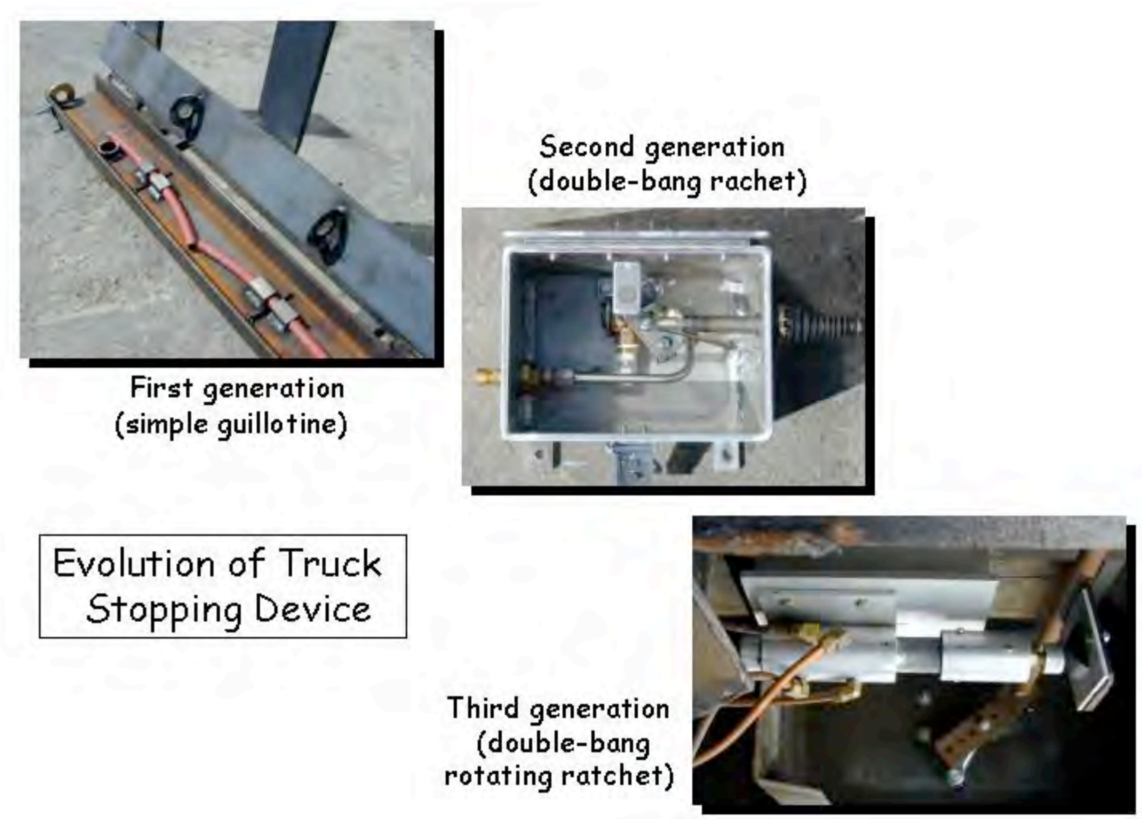


Figure 3: The above three pictures show the first three prototypes of the rear impact truck stopping device (TSD) that sets the brakes on a truck or trailer when the device is lightly bumped by a patrol car. These units were developed in order to find the best way to set the service brakes on a truck. Electronics was then added to achieve the remote-controlled CAPS.

Top left: The first TSD simply cut an embedded air hose when the top gate is impacted. The gate is shown open here to show the two sharpened cutting washers and the embedded air hose on which they impinge when pushed forward.

Middle: The first TSD that required two or more impacts before it set the brakes on the vehicle to which it is attached.

Bottom: The final, inexpensive third generation double-bang TSD that is totally contained in a simple sealed cylindrical unit called a spiral ratchet mechanism. Two impacts at the right side of the unit causes an internal spool valve to direct air pressure to the truck or trailer control valve that sets the service brakes on the vehicle.

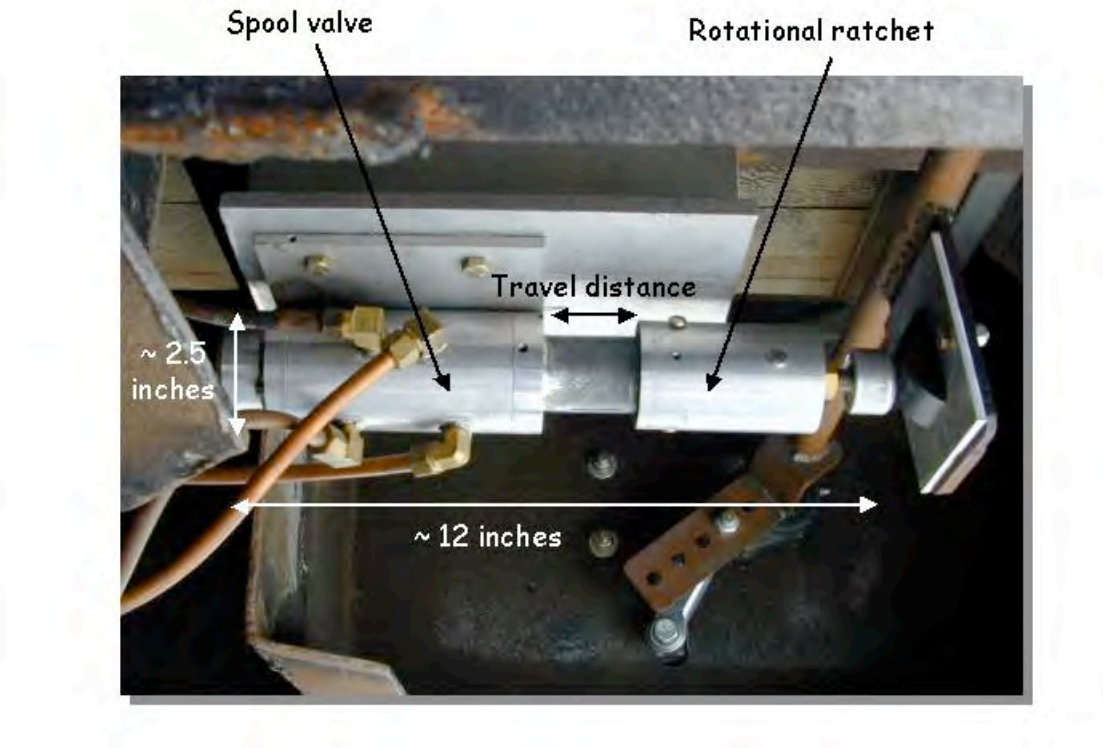


Figure 4: An expanded view of the production version of the simple spiral ratchet TSD. The impact plate is on the right. On the left side, air lines can be seen going into and leaving the internal spool valve assembly that activates the truck's brakes when the right side is pushed in twice by light impacts on the truck's rear bumper.

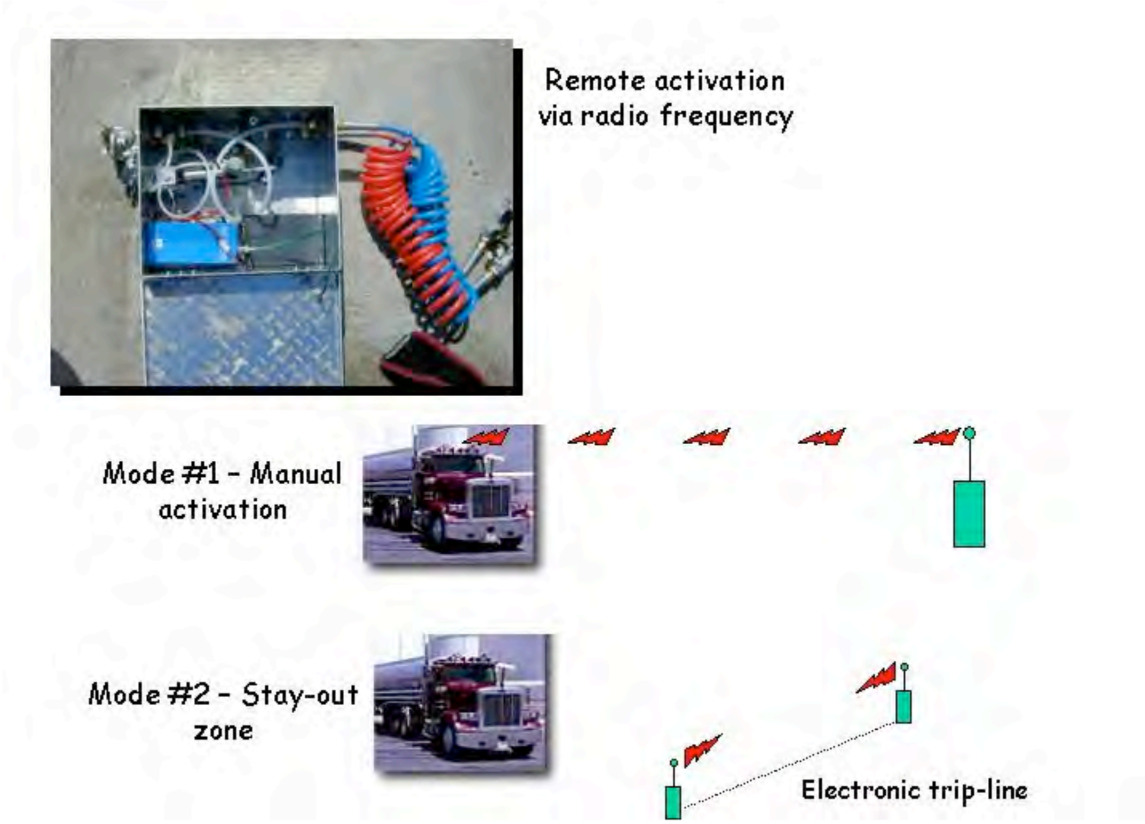


Figure 5: The remotely operated CAPS truck stopping device (TSD). The silver box at the top (the size of a shoe box) contains an electrically operated air valve that can set the brakes on any vehicle on which the CAPS unit is connected. The unit is portable and can be temporarily installed in less than a minute on any truck entering a critical area. Thereafter, the movement of the truck is under the positive control of security personnel who can stop the truck anytime by punching a button on a transmitter shown at the upper right, mode #1.
Mode #2 operation stops the truck any time it approaches a forbidden area that is marked off by a linear antenna that is constantly radiating a stop signal, as shown at the trip line in the lower right corner. Mode #2 operation is often called "electronic fencing."

Figure 6:
A security officer at LLNL is holding a button switch in his hand which he used to stop the truck. The button activates the transmitter shown in figures 1 and 5. The button-activated transmitter radiates a wide-area coded signal that activates the CAPS unit mounted on the truck to set its brakes.

In all cases shown above, the truck driver is helpless to release the brakes from the cab of the truck once they have been activated by the CAPS unit mounted between the truck and trailer. The brakes remain set until a security person resets the CAPS unit with a special code.

Figure 7:
Picture of a rear impact truck stopping (TSD) test with a commercial fuel tanker truck. The TSD is mounted behind a standard hazardous notice placard on the rear bumper of the trailer. This truck-trailer combination belonging to Benito Tank Lines, Sacramento , Ca., was fully loaded with 9000 gallons of gasoline. It was driven at 50 mph on the CHP test track at Sacramento, Ca, by the company's chief driving instructor. This truck and trailer always stopped gently, but firmly without tires skidding because the trailer was fully loaded. (The light skid marks on the pavement were not created by these tests.)
CHP officers in standard CHP patrol cars repeatedly chased and stopped the truck by lightly impacting the rear bumper. The loaded truck and trailer always stopped in a stable, straight-ahead manner because the TSD only sets the brakes on the rear axles of the trailer, not the truck. This means that the trailer will not jack-knife as might be the case if the truck brakes are also activated. However, these tests also included attempts by the driver to induce jack-knifing. In two tests, the truck driver applied maximum braking from the cab as soon as he felt the stopping action of the activated TSD. (This is something that an inexperienced hijacker might do in a panic response to the stopping action that he does not understand or control.) Even under this extreme circumstance, the truck did not swerve dangerously and the trailer did not jack-knife because the trailer brakes had been applied before the truck brakes. These tests were filmed on video and are available on CD or the Livermore Lab website.
The project personnel spent thirty two days working on and testing the TSD mounted on this commercial fuel tanker truck operating over the road every day. There have been no operational failures of the TSD installed on this truck in sixteen months of continuous operation. The ability of a police patrol car to stop this truck at will has been tested about every sixty days.

Live action video clips of all the TSD field tests done over the last three years on high speed trucks being stopped by police patrol cars and the remote controlled CAPS version can be seen at the bottom of the home page on the UC Lawrence Livermore National Laboratory website at: www-eng.lnl.gov\tsd\tsd.html

Figure 8:
Various prototypes of the truck stopping device are shown to the press at the public demonstration on February 22, 2005, at the University of California Lawrence Livermore National Laboratory. The silver box on the table in the right foreground is the portable, remote-controlled CAPS unit mounted on the truck during the demonstrations. W.H.Wattenburg, right, is holding and showing the small double-punch spiral ratchet mechanical unit that is used in the latest mechanical rear impact version of the truck stopping device. This simple device made it possible to achieve an inexpensive remote-controlled version of the TSD call CAPS (for Critical Area Protection System).

Live action video clips of all the TSD field tests done over the last three years on high speed trucks being stopped by police patrol cars and the remote controlled CAPS version can be seen at the bottom of the home page on the Livermore Laboratory website at:

www-eng.llnl.gov\tsd\tsd.html

(Be sure to type the www “dash” eng….. as shown in the URL above. If you swipe the URL above and then paste it into your browser window, some browsers will replace the www “dash” eng…. with www “dot” eng…. That will not work)

SOLVING MAJOR TERRORIST VULNERABILITIES

By Dr Bill Wattenburg

Within hours of the World Trade Center attack, a group of scientists from California State University, Chico, the University of California Lawrence Livermore National Laboratory and the California Energy Commission began considering the most probable targets for continued terrorist attacks.

National attention was focused on airplanes and airport security, but it was likely that terrorists would choose other targets and other means if they struck again. We recognized several vulnerabilities that had to be addressed immediately. At the top of our list of targets open to attack were the major bridges used by thousands of people every day. Next were the thousands of fuel tanker trucks on our highways, any one of which could be hijacked and used as a truck bomb with the explosive power of a large airliner. Third were the security perimeters around our power plants and electrical grid facilities, many of which could easily be breached by truck bombs.

The weak spot in suspension bridges

Security experts have long been aware that bridges can be damaged by car or truck-bombs driven onto the structures. John Nuckolls, well-known scientist and former Director of the Livermore Laboratory, insisted that we must find out immediately if terrorists could do great damage to our major suspension bridges with much less than large truck bombs on the roadways. I immediately called a scientist at Livermore, Dr David McCallen, who is an expert on the structural design of the Golden Gate and Bay Bridges. For years, he had been using the large computers at the Livermore Lab to analyze how these bridges and other structures can be damaged by earthquakes.

Dr McCallen told me that he had spotted a serious weakness in the Bay Bridge months before 9/11. He said he had told the bridge engineers, who replied that they "had no budget to do anything about it right now." The glaring weakness he described was that almost anyone could gain access to the anchor points at the ends of the suspension cables that hold up the entire bridge. The rooms where the cable anchors are located were essentially wide open and unguarded – in fact, some were occupied by the homeless at night.

At the ground anchor points at each end of the suspension cables, the big cables separate out into dozens of small bundles of cable strands. Each small cable bundle is tied to its own anchor bolt, which is in turn embedded in the massive concrete anchor blocks in the ground. A terrorist with the right tools or a small amount of explosives could cut the smaller cable bundles at the anchor points in just a few hours. If enough cable bundles at the end of one suspension cable were severed by any means, the entire suspension bridge would collapse.

I called the top police officer for the State of California, California Highway Patrol (CHP) Commissioner Spike Helmick at his home. As soon as I explained the danger, Helmick ordered his armed patrolmen to guard the anchor buildings on all the state's suspension bridges, day and night. Over the next seven weeks, California Department of Transportation (Caltrans) engineers installed concrete doors and fences around all access points to the cable anchor rooms on these bridges. A street in San Francisco beneath the Bay Bridge was closed to traffic because it allowed a vehicle carrying a bomb to come too close to the cable anchor rooms at the end of the bridge.

There was a news blackout on this work until it was finished. The federal Homeland Security Office was notified so that other states with suspension bridges could be warned. The completion of work was announced on November 1, 2001 by Commissioner Helmick, but only after he was sure that other states had been able to check their own bridges.

(from left to right) Senator Harry Reid, former FEMA Director Joe Allbaugh, Secretary Tom Ridge, General John Gordon and Bill Wattenburg at the Nevada test Site.

The truck-Stopping device brings trucks to a screeching halt.

Light impact on the bumper causes the air brakes on the truck to be applied with maximum force.

Stopping hijacked trucks on the highways

In early October 2001, while the bridge work was underway, I asked Commissioner Helmick what his patrolmen could do to stop truck bombers from traveling on the bridges. His terse response dripped with frustration: "Hell, we can't even stop a hijacked big truck on the open highways. How can we do anything about a hijacked fuel tanker truck that is heading toward a bridge?"

He explained that there are really no effective procedures available to police officers around the country that allow them to stop a hijacked big truck swiftly and safely, even if a dozen police cars are following the truck. Runaway big trucks can continue for hours after they are intercepted by police cars, and police can do little but follow them until they run out of fuel or some other event stops them. A speeding 80,000lb truck can crash through barriers and knock police patrol cars around like Tonka Toys.

I was surprised. I knew that many millions of government dollars had been spent over several decades on various high-tech schemes to control trucks on the highways. Commissioner Helmick explained that none of the electronic schemes proposed over the years had gained approval of the trucking companies or the police departments. These schemes were too complex, too expensive, too easily defeated – or all the above.

Then Helmick made the observation that forced us to focus on the real problem and find a workable solution. He said: "Look, a police officer on the road has only three tools he can use today. He has his patrol car. He has his weapon. He has his life. We need to find some way that any police officer can use his patrol car or his weapon as they exist today without risking his life. And, we have to have something simple and reliable that can be installed on all trucks without great expense. It has to be something truck drivers can understand. Otherwise, the trucking industry will never accept it."

That made us go back to basics. When I was younger, I drove and repaired my father's big trucks in his construction company. The next day I crawled under a big rig. I was thinking of ways to stop a truck (by schemes such as blowing out the tires, locking up the drive line or maybe cutting the fuel lines) when I noticed a standard device that is installed on all big trucks and trailers: the air valve that controls the air brakes. There was the answer right before my eyes. All we had to do was devise some way that a pursuing police car could activate this air valve from the rear of the truck or trailer. The truck's air brakes would be applied as if the police officer had jumped into the cab of the truck and stepped on the brake pedal. The truck would come to a screeching halt, and the hijacker would be helpless to do anything about it.

I sketched out the design for a simple mechanical device that could be mounted on the rear of any truck or trailer. It was a modified bumper that could be safely impacted by any police car following the truck. This bumper was hooked up to the air valve under the truck or trailer in such a way that a light impact on the bumper caused the air brakes on the truck or trailer to be applied with maximum force. The truck's air brakes were locked on until someone crawled under the truck and reset this truck-stopping device. A few hours later, a clever mechanic in my shop had built the device, mounted it on a semi-trailer and connected it to the trailer's standard air brake valve.

We did the first tests that afternoon on a nearby county road. We bumped the rear of the trailer with a pickup truck as a truck pulled the trailer down the highway at 50mph. The truck came to an immediate controlled stop, and the trailer brakes were locked up in such a manner that the driver could not override them from within the truck cab. At any time, there are at least 20,000 fuel tanker trucks unloading fuel at service stations and/or rolling on the highways of the US, and fuel tanker trucks are the biggest potential truck bombs that could be hijacked by terrorists. After seeing the truck-stopping device in action, Helmick and California's Director of Homeland Security, George Vinson, said: "We want that as soon as possible on fuel tanker trucks."

A task force called "The Governor's Task Force for the Safe Delivery of Fuels" was established immediately with representatives from the California Highway Patrol, the trucking industry, the oil companies and the driver's unions. New procedures were adopted to protect fuel trucks from being hijacked. They agreed that the truck-stopping device (TSD) should be improved and field-tested as rapidly as possible to give police officers a chance to stop a truck if it is hijacked. Trucking industry and union representatives requested a number of design changes to improve the reliability and safety of the TSD. Governor Gray Davis asked the Lawrence Livermore National Laboratory to assist the state in this project. The Laboratory Director, Bruce Tarter, and the Chief Executive Officer, Ron Cochran, ordered work to begin immediately with laboratory funds. State funds were delivered to the Livermore Laboratory the following week.

High-speed tests began in January 2002 at the Nevada Test Site with remotely controlled big trucks. We developed versions of the TSD that embody several anti-tampering and anti-vandalism features. These TSDs are not activated by accidental rear end collisions. They cannot be easily disabled by a terrorist without locking on the brakes of the truck so that the truck is inoperable when the terrorist attempts to drive off. A vandal who impacts the TSD on the rear of a truck for any reason will have his vehicle (or his body) marked by fluorescent dye that will easily identify him or his vehicle.

The first installation on an over-the-road fuel tanker truck owned by the Benito Trucking Company, Sacramento, California, was completed in December 2002. We are now testing radio controlled and portable versions of the TSD that can be attached temporarily to trucks entering critical areas. The California Highway Patrol has demonstrated the TSD to top security officials from other states and federal agencies. Most have expressed interest in using this technology. The California State Legislature is now considering legislation to require truck-stopping apparatus on all trucks carrying fuel and dangerous materials operating in the state. Worldwide patent applications covering this truck-stopping technology have been filed by the University of California Lawrence Livermore National Laboratory, and the Lab is now seeking companies interested in manufacturing and supplying this apparatus to the trucking industry.

One would think that some federal agencies would have rushed to provide funding for quicker delivery of this demonstrated solution to a national terrorism vulnerability. It did not happen. We are still waiting for some federal help to install more units and conduct more extensive field tests.

An inexpensive and portable vehicle barrier for stopping truck bombers

Truck and car bombs are favored tools of terrorists. A large truck can breach the fences or break the concrete barriers that surround many critical installations, and often the truck can travel a long distance before it explodes at a target. This must be prevented. Another major problem is that most security checkpoints must allow cleared vehicles to pass through. The guards have no way to stop renegade vehicles that charge the checkpoint at the last second. The guards are often killed when a car bomb explodes near them.

Lawrence Livermore National Laboratory scientists and engineers searched for a simple and inexpensive vehicle barrier that could solve these problems. They chose an uncommon steel pipe vehicle barrier that was originally designed as a movable traffic barrier for multi-lane bridges and freeways. Earlier tests had shown that the wheels of a car will not easily roll over the round pipe.

Appendix III to Final Report

California Energy Commission
Contract 500-00-018
March 30, 2005

Vehicle Barrier Constructed from
Round Steel Pipe

W.H. Wattenburg
University Foundation
California State University, Chico

With Joint Venture Partners:

David McCallen
Center for Complex Distributed Systems
Lawrence Livermore National Laboratory

Patrick Lewis
Defense Sciences Engineering Division
Lawrence Livermore National Laboratory

Pete Mote
Nevada Testing Institute
Las Vegas, Nevada

Abstract

The threat of terrorist vehicle bombs has become evident in the past few years. The explosive power that can be generated by a 'home made" bomb carried by a standard van or moderate size truck can generate sufficient blast overpressures to cause major damage or catastrophic collapse to building structures. The sections below describe a simple but very effective vehicle barrier made of round steel pipes sections which can be used to prevent unauthorized vehicle access. Field testing reported and shown herein demonstrated the ability of the pipe barrier to effectively stop speeding vehicles by flipping them over. This defeats truck bomber strategies that can catapult explosive devices some distance beyond standard barriers that stop a truck at the barrier surface.

1.0 Background

Recent events in the U.S. and abroad have demonstrated the potential for terrorist vehicle bombs to cause massive destruction to important facilities (Table 1).

TABLE 1. Terrorist attacks against U.S. assets, 1983-1998.

Terrorist Event	Casualties
1983 Car Bomb, U.S. Embassy, Lebanon	63 killed
1984 Car Bomb, U.S. Embassy, Lebanon	11 killed
1986 Bomb, La Belle Disco, Germany	2 killed
1993 Car Bomb, World Trade Center, USA	6 killed, 1000 injured
1995 Car Bomb, U.S. Barracks, Saudi Arabia	7 injured
1995 Car Bomb, Federal Building, USA	168 killed
1996 Car Bomb, U.S. Barracks, Saudi Arabia	19 killed
1998 Car Bomb, U.S. Embassy, Tanzania	11 killed
1998 Car Bomb, U.S. Embassy, Kenya	213 killed, 5400 injured

The effects of a vehicle bomb on a major structure can range from destruction of the cladding (i.e. the non-structural wall elements) of the structure, to progressive collapse of the structure. Progressive collapse occurs when a bomb blast causes sufficient local damage to the structure that the vertical gravity load path of the structure is destroyed and the gravity loads on the structure then lead to overall collapse of the structure (Figure 1). The structural system type can play a large role in determining whether or not progressive collapse occurs. The attack at the Murrah Building in Oklahoma City for example resulted in progressive collapse of a large portion of the building structure (Figure 2). The Murray Building was a reinforced concrete frame structure and the vehicle bomb caused extensive local destruction of the columns and the vertical gravity load path was destroyed locally. The existing frame system was incapable of redistributing the gravity load, and vertical collapse of the frame structure ensued. A similar attack occurred on the Khobar Tower building in Saudi Arabia (Figure 2). However, this structural system consisted of a shear wall lateral load system as opposed to the frame system of the Murrah Building. The result was that the powerful bomb caused extensive failure of external cladding, but the vertical load system was not severely damaged and the structure did not suffer progressive collapse.

The extensive damage caused by terrorist bombs is a result of the tremendously large overpressures which can be generated by a bomb created from readily obtainable commercial use materials. For example, the overpressures created at various distances for an explosive equivalent to 5000 lbs of TNT are shown in Figure 3. A terrorist can create this level of

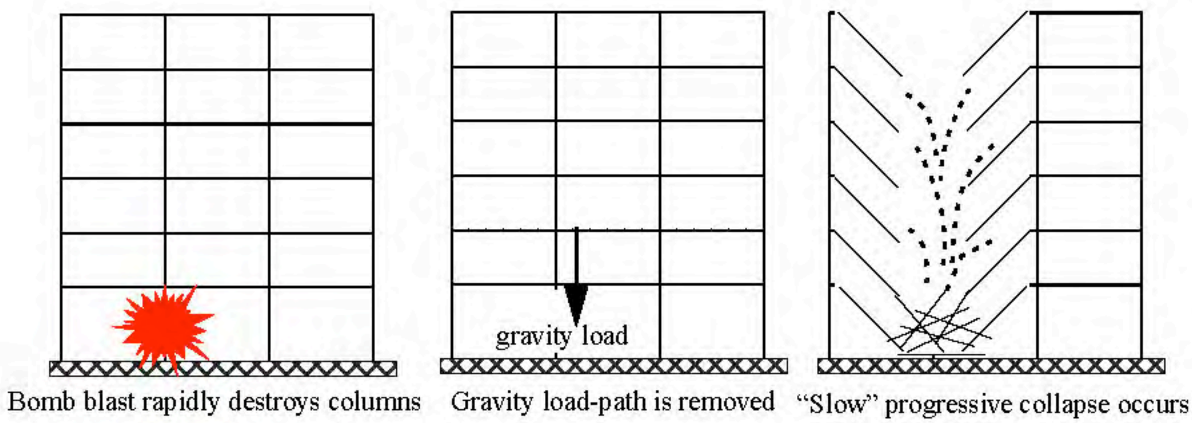


FIGURE 1. Progressive collapse of a building.

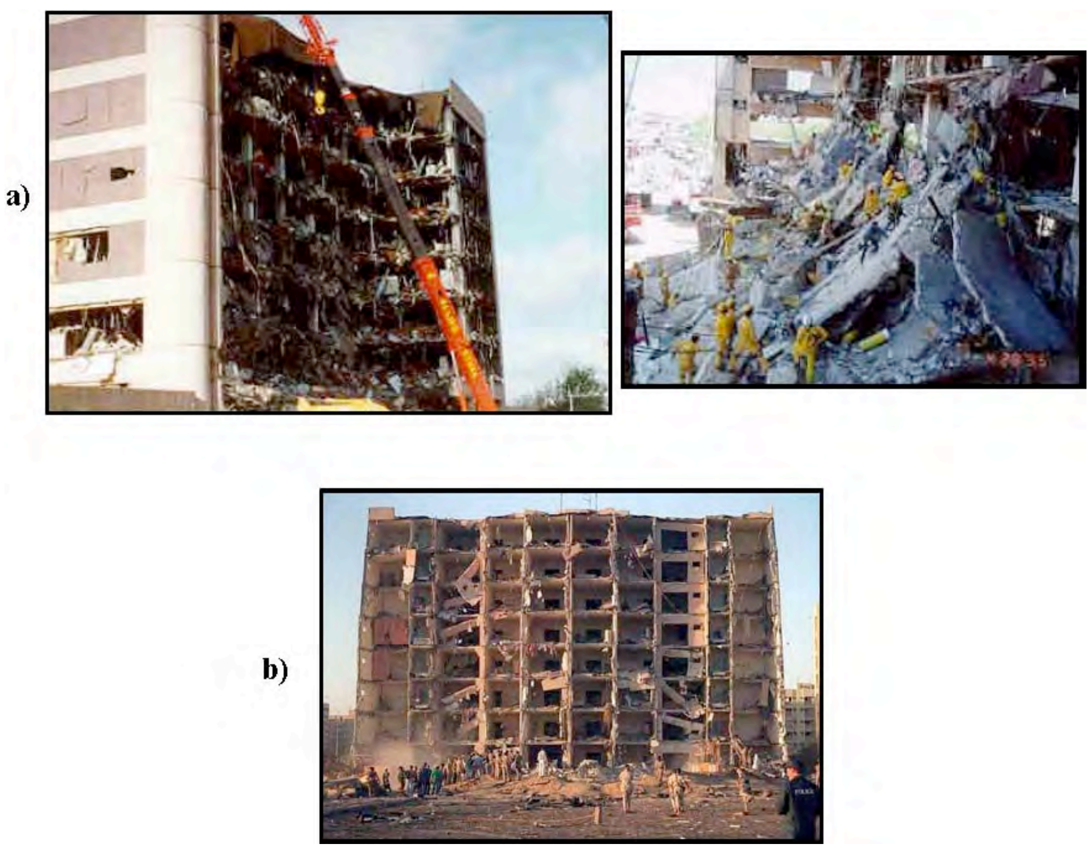


FIGURE 2. Terrorist attacks on U.S. infrastructure. a) Domestic terrorist attack on the Murrah Building, Oklahoma City resulting in progressive collapse; b) terrorist attack on the Khobar Tower Building, Saudi Arabia, resulting in extensive cladding destruction.

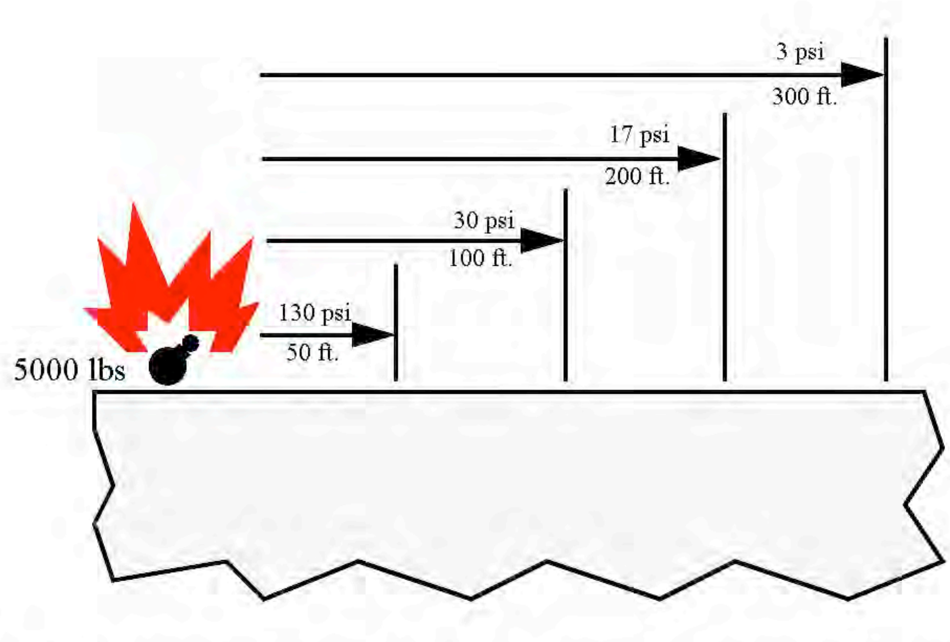


FIGURE 3. Blast overpressures as a function of distance for a bomb equivalent to 5000 pounds of TNT.

explosive with ammonium nitrate and fuel oil (ANFO) materials. Typical building structures may survive overpressures in the 2-3 psi range, but will likely be destroyed by overpressures on the order to 10-15 psi. Thus Figure 3 indicates that a significant stand-off distance must be maintained in order to protect a structure from a powerful vehicle bomb. This is obviously not feasible for many structures, such as important buildings located in downtown locations. However, for some important facilities, such as nuclear power plants, significant stand-off distances are achievable. Even for facilities where adequate stand-off cannot be achieved, maximizing the existing stand-off can assist in protecting the occupants.

The possibilities for stopping unauthorized vehicle access to critical facilities consist of human intervention, where armed guards are posted to prohibit passage, or physical barrier placement where a mechanical system is placed to prevent unauthorized vehicle passage. The human intervention alternative has proven a number of times to be an ineffectual method. Our notion of what represents rational behavior indicates that highly armed guards would provide a significant deterrent to a terrorist. However, a determined terrorist, willing to sacrifice his own life, is undeterred by bullets and bullets are ineffectual in stopping a speeding vehicle regardless of how many of the bullets strike the driver. In the attacks in Lebanon and Africa, armed guards were aware an attack was underway, but were unable to deter or prevent the attacks.

A number of possibilities exist for creating a physical barrier. However, there are often conflicts between limiting access for unauthorized vehicles and allowing access to authorized vehicles. The most widely used method of denying access is through the use of concrete rail barriers such as those found along highways (the most familiar being the "New Jersey" barrier denoting the state where it was originally designed and constructed). These massive concrete barriers can be very effective in stopping vehicles, however, they are massive and heavy, which requires the use of heavy equipment for placement. Once placed, the barrier can only be moved by bringing in heavy lifting equipment, and cannot be quickly changed to allow access status for authorized vehicles. In addition, these barriers may not be available in any location where a quick barrier is required, particularly at overseas sites where critical facilities or rapidly deployed forces might require short notice protection.

The purpose of the feasibility study described herein was to investigate the utility of a new alternate vehicle barrier concept. The alternative barrier, originally proposed by W.H. Wattenburg, consists of a steel cable strung through steel pipes and anchored on the ends as shown in Figure 4. The barrier can be constructed from readily available materials, which

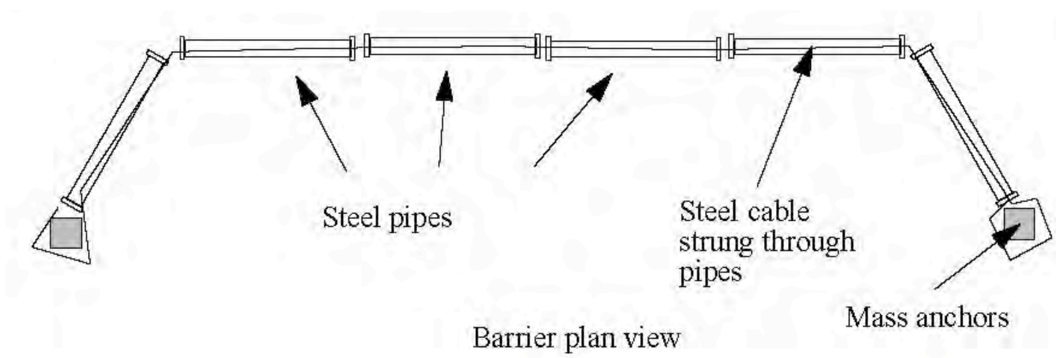


FIGURE 4. Flexible pipe barrier concept.

are obtainable essentially anywhere in the world, without the use of heavy equipment or specialized construction skills. The barrier is very light relative to concrete rail barriers and with the appropriate connection couplings, segments of the barrier could be moved by hand in a matter of minutes. The barrier is flexible. It provides some "give" when impacted by a speeding vehicle. The end masses provide the anchors for the cable system and react the inertial forces resulting from the vehicle impact. This barrier concept was tested with field experiments at the hazardous spill facility at the DOE's Nevada Test Site (NTS) north of Las Vegas.

2.0 Evaluating the pipe barrier concept

The pipe barrier concept was tested at the hazardous spill facility at NTS. The principal objective of this test was to ascertain the ability of the barrier to incapacitate a large speeding vehicle. Because of the remote location, and the availability of a flat wide open area, the NTS facility provided an ideal test bed for the barrier concept, and allowed for performance of a destructive test where the vehicles could be smashed into the barrier at high rates of speed.

The vehicle test area is shown in the photograph in Figure 5, this area provided an unrestricted vehicle run-up of approximately 600 ft. The site also had barrier construction

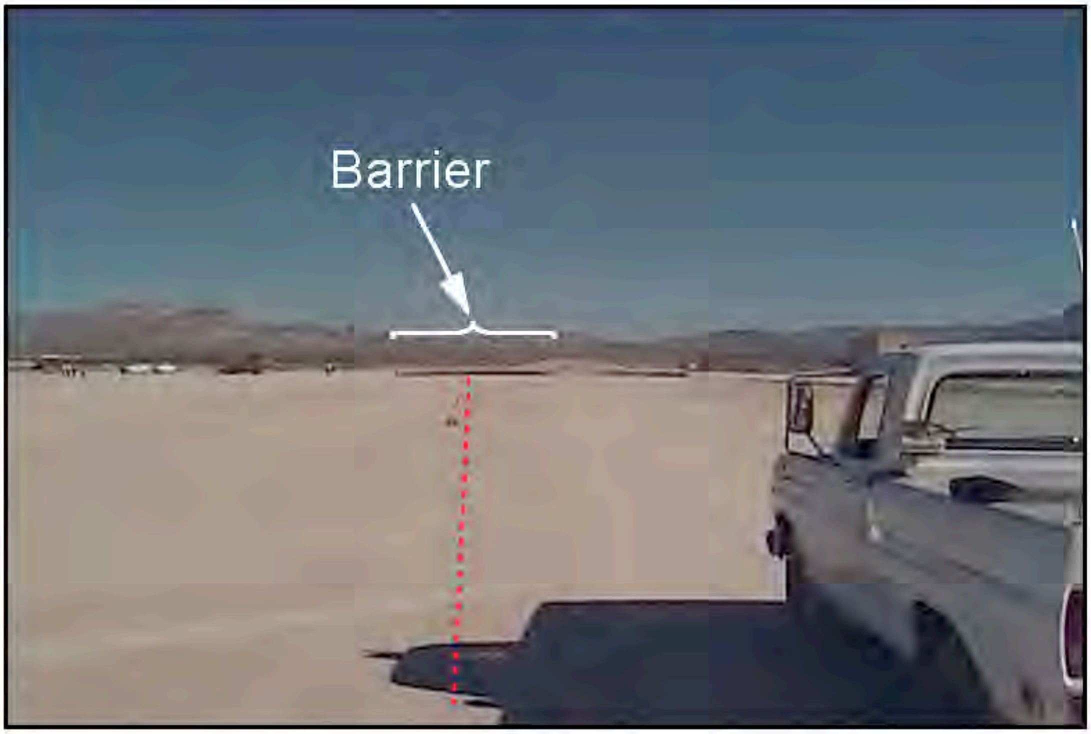


FIGURE 5. Vehicle run-up at the NTS spill facility.

materials available and two excess DOE vehicles were obtained from the NTS motorpool to serve as mock terrorist vehicles. The barrier was constructed with 24 inch steel pipe and one inch diameter steel cable. Existing concrete blocks were utilized as anchors at the ends of the barrier as shown in Figure 6. Since an objective of the experiment was to crash the vehicles into the barrier at high rates of speed, human drivers were out of the question and a remote control vehicle system was developed. The vehicle control system consisted of a radio commanded electronic control system mounted in the rear of the vehicle. The

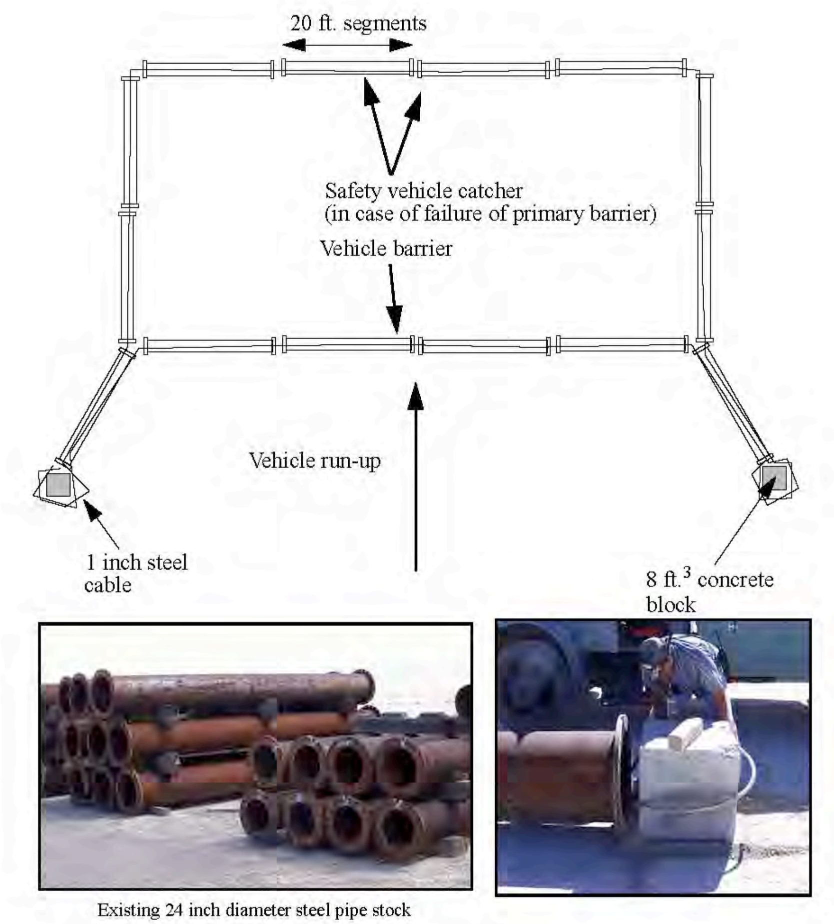


FIGURE 6. Test set-up for the pipe barrier experiments.

control system sent commands to a system of servos and linkages in the truck cabs which controlled steering, gas pedal, and brake as shown in Figure 7. Safety was of paramount concern and special redundant safety features were included on the vehicle. The safety aspects included an ignition system kill from the radio control box, a “time-out” timer on the vehicle which would kill the ignition system after a specified number of seconds, an accelerometer triggered ignition kill feature which would kill the ignition system after the accelerometers sensed large accelerations associated with impact, and finally the original vehicle fuel tanks were stripped from the vehicles and replace with a one gallon lawn mower tank to limit the fuel on board and minimize any fire hazard (Figure 7).

The field experiments consisted of running the vehicles into the barriers at speeds which were representative of what a terrorist vehicle bomb could practically achieve prior to impacting a barrier. Two experiments were conducted. In the first experiment a 3/4 ton truck loaded with approximately 500 pounds of sand bags to mock a bomb mass was crashed into the barrier at approximately 35 miles per hour. In this first experiment the vehicle hit the barrier with tremendous impact and was effectively launched into the air.

Inspection of the vehicle indicated that the initial impact resulted in the motor shearing from the motor mounts and smashing up into the vehicle radiator. The initial impact also resulted in rupture of the vehicle drive line just behind the vehicle transmission. The destroyed vehicle came to rest right-side-up approximately 35 ft. beyond the original barrier location. Initially it was thought that leaving some slack in the cable would allow the barrier to translate somewhat and potentially allow the barrier to snag the vehicle in the barrier system. Careful slow-motion visual inspection of this first experiment provided some insight into the details of the interaction between the barrier and the vehicle. From the slow motion animation, it was clear that the vehicle moving at high speed impacts the barrier and is essentially launched in a vertical direction before the pipes in the barrier have enough time to respond and begin to move. Thus the slack which was purposefully left in the barrier cable during this first test was not utilized by the deforming barrier until the vehicle was long gone over the barrier. In light of this observation, the cables were brought to a taut configuration for the second vehicle experiment so that the impact would maximize the vehicle damage due to initial impact.

The second vehicle test utilized a one ton truck moving at approximately 42 miles per hour. Like the first experiment, this vehicle was loaded with approximately 500 pounds of sand to emulate some explosive weight in the bed of the truck. With the taught cable system, the barrier was stiffer and the when the truck attempted to bounce over the barrier, the taught cable system launched the rear of the vehicle vertically in addition to the front of the vehicle, the result being the vehicle totally flipped as it traversed the barrier as shown in Figure 9. The vehicle also exhibited the same power train damage characteristics as the first vehicle test, including a sheared off motor and broken drive shaft. A sequence of video segments illustrating the vehicle-barrier impact are shown in Figure 10.

3.0 Conclusions

This pipe barrier can be utilized to disable heavy duty, speeding terrorist vehicles. The experiments indicated that a vehicle impacting this barrier at speed will be flipped over and land on its top not far from the barrier. This is highly desirable to defeat a "catapult" strategy sometimes used by truck bombers who expect the truck to be stopped abruptly by a very heavy and rigid barrier. An explosive load in the back of an open-bed truck such as a pickup can be positioned to catapult over the cab of the truck and fly some distance beyond the rigid barrier. Everyone has experienced the large dynamic forces which result when a relatively small highway speed bump is hit at slightly too high a speed (say 8-10 m.p.h.), extrapolate that to a much larger "bump" and higher speed and a physical intuition of the level of forces at play in the barrier impact can be developed.

a)

b)

FIGURE 7. Test vehicle hardware. a) Electronic controller and control servos and linkages; b) safety features including reduced gas reservoir and accelerometer for ignition kill.

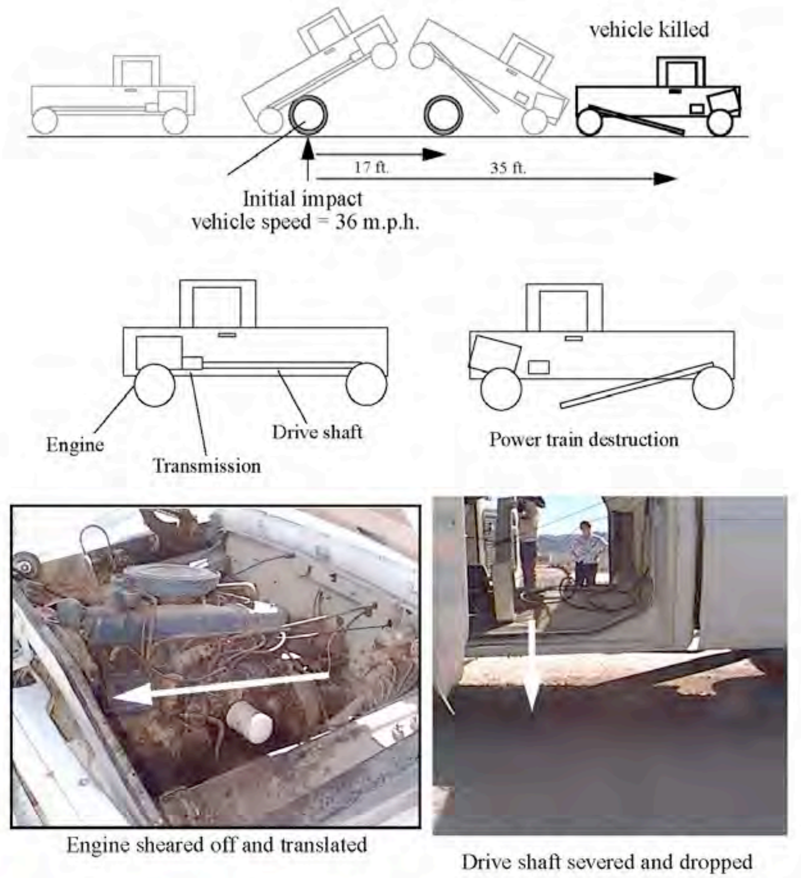


FIGURE 8. Vehicle destruction from the first vehicle experiment.

The pipes used in the field experiment were 24 inches in diameter and this diameter was employed because of the availability from the existing pipe stockpile at NTS. With this diameter pipe, the bumpers of the trucks impacted near the top of the pipe. As a result, the vehicles tended to be launched vertically upon impact and flip over. So, although the vehicles were completely disabled, they did physically end up beyond the barrier. It is likely that a larger diameter pipe, 36 inch pipe for example, would have less tendency for sending the vehicle in the vertical direction and would result in a more violent collision, with more energy

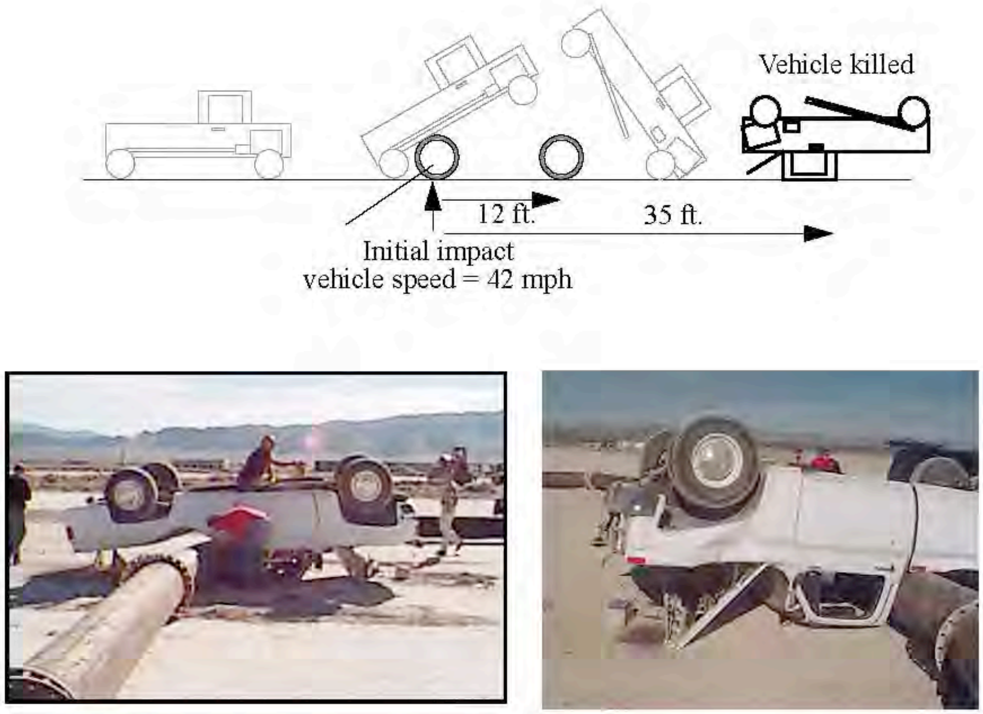


FIGURE 9. Vehicle destruction during the second field test.

transferred to the vehicle system, and would tend to snare the vehicle in the barrier rather than allow the vehicle to vault vertically and move over the barrier. In order to optimize the barrier design for applications where the vehicle must be stopped before vaulting the barrier it would be desirable to test larger diameter pipe barriers in the future.

This pipe barrier should not necessarily be viewed as a replacement for standard concrete barriers for all applications. However, where a need arises for a quick and easily constructed barrier, which must be constructed from readily available materials on hand, this barrier design can be very useful to deny unauthorized vehicle access. The barrier also has potential for applications in which there is a mixed need for authorized vehicle access and unauthorized vehicle denial, where the barrier must be moved and replaced at frequent intervals.

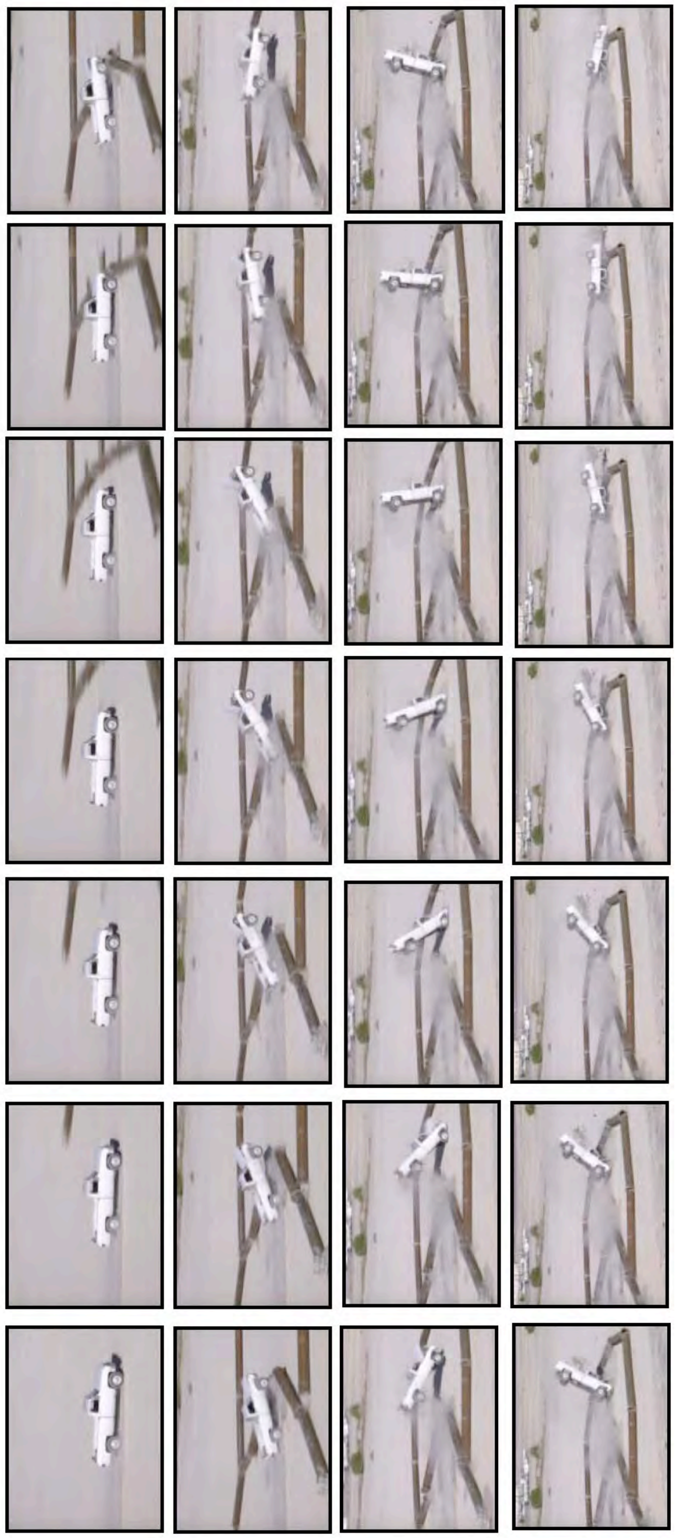


FIGURE 10. Sequence of frames showing vehicle -barrier impact during the second vehicle test.

Appendix IV to Final Report

California Energy Commission
Contract 500-00-018
Dr. Bill Wattenburg
Principal Investigator
March 30, 2005

Emergency Voltage Reduction (EVR) to Respond to Power Emergencies - An Unanticipated Discovery

Emergency Voltage Reduction Experiments, Proposals, and Utility Company Reactions During the California Energy Crisis 2000-2001

The principle investigator believes that the recognition that EVR could be used during the California energy crisis of 2001 and the governor's announced plans to implement it may well be the most valuable results of the contract 500-00-018 work. It was proven that EVR can be used to respond to power emergencies and avoid the necessity of using rotating blackouts to reduce demand on the grid (which was the main objective of this contract work in 2001). EVR could be used to prevent major grid collapse in California in the future.

Contents:

The following draft press release from the governor's office on June 28, 2001, best tells the story of how Emergency Voltage Reduction (EVR) was recognized as a way to avoid blackouts or grid collapse during the energy crisis of 2001. This press release was based on the recommendation of ENERGY COMMISSION Commissioner Arthur Rosenfeld on June 22, 2001 (see Section 5 herein). The governor's office held a state-wide press briefing by telephone conference call on July 3, 2001. The principal investigator, W.H. Wattenburg, was asked to represent the ENERGY COMMISSION during this press conference and present the technical details of the EVR plan recommended by the ENERGY COMMISSION and proposed by the governor.

June 2001
Draft press release from the governor's office:

Roger, I ran this by Commissioner Rosenfeld for technical accuracy via phone. His changes are in CAPS so that you can find them in this e-mail. He will also look at it when he gets back into the office.

Basically they reflect:
1) SMUD and LADWP are included in this project;
2) we are reducing the voltage to historic levels
3) there will be little noticeable (rather than no)
4) this will result in a reduction in consumer electricity use (rather than talking about the electricity bills or the 2.5% reduction which he says is actually a 1% reduction)

PR01 xxx

FOR IMMEDIATE RELEASE **CONTACT: Steve Maviglio**
June xx, 2001 **(916) 445-4571**

GOVERNOR DAVIS ASKS UTILITIES TO IMPLEMENT VOLTAGE REDUCTION MEASURES

SACRAMENTO @ Citing a series of successful tests conducted by the state's investor-owned utilities, SMUD, LADWP and the California Energy Commission (ENERGY COMMISSION), Gov. Gray Davis today asked the state's major utilities to propose and implement minor voltage reductions to save up to 500 megawatts of electricity during peak demand periods.
"Through this initiative, we can reduce demand by as much as the capacity of one major power plant," Governor Davis said. "Extensive testing has shown that not only can we safely reduce demand by reducing voltage, but we can do so in a way that is safe and will save Californians money.
Under this plan, the investor-owned utilities would reduce voltage to customers by 2.5 percent, REDUCING the voltage TO historic levels. While this minor 2.5 percent reduction in voltage will have no impact on appliance performance, it will result in A reduction in customer CONSUMER ELECTRICITY USE.

The voltage reduction initiative was spearheaded by ENERGY COMMISSION Commissioner Arthur H. Rosenfeld, who assembled a team of engineers and scientists to investigate several ways to avoid rotating blackouts and save electricity. The team is led by Dr. Bill Wattenburg, a consultant to the Lawrence Livermore National Laboratory and includes top engineers from PG&E, SCE, and SDG&E. For the past two months, they have been working at the PG&E Technical Center in San Ramon where they have assembled extensive test facilities for measuring utility load reduction procedures.

Wattenburg initiated tests on typical homes and commercial equipment with voltage drops considerably larger than 2.5 percent and found that the power demand dropped with no danger whatsoever to home appliances or commercial equipment. Indeed, the engineering team discovered that all home appliances and most commercial equipment operated more efficiently at 110 volts than at 120 volts.

The investor-owned utilities, with the permission of the California Public Utilities Commission (CPUC), have historically set customer voltage levels between 114 and 126 volts. This provided a large system reliability cushion, and ensured that voltage did not drop below 114 volts, even in outlying areas where voltage occasionally sags.

In the late 1970s, in response to an earlier electricity shortage, the CPUC required the utilities to drop the upper end of the voltage range, where feasible, to reduce electricity usage. This new initiative will expand and extend the existing measures to provide additional demand reductions during the critical peak summer period this year.

Voltage reductions of 3-5 percent have been successfully implemented during emergencies in several states. Governor Davis is asking the CPUC to review the actions that it may need to take to facilitate and expedite the utilities' plans.

"This program, combined with the new power plants we are building, our aggressive conservation effort, and the long-term contracts we have signed, will help us minimize disruptions this summer," Governor Davis said.

(end draft press release)

The files in the governor's office contain a transcript of the state-wide media conference call on July 3, 2001, that followed this press release. Memos between the California Energy Commission, the governor's office, and the principal investigator in June 2001 which describe the planning for the EVR proposal are contained in the sections below. These documents are all non-confidential public documents in the files of state agencies. They are relevant to why and how EVR was justified and proposed to solve the power emergencies during the 2001 California energy crisis. This information is valuable to political leaders and the public who will have to find and evaluate potential solutions to power emergencies in the future.

1. The Recognition of Emergency Voltage Reduction

During April and May 2001, the principal investigator worked with the Pacific Gas and Electric Company (PGE) at their San Ramon Technology Center to conduct extensive low voltage laboratory tests to evaluate the performance of an energy saving device called the Wattenburg Load Reduction Switch (LRS). This project was requested by the California Energy Commission (later authorized by ENERGY COMMISSION contract 500-00-018 on May 29, 2001). PG&E and the principal investigator, W.H. Wattenburg, agreed to start this work in April 2001 and work at their own expense well before a contract could be finalized because the energy crisis was costing the state over a billion dollars a month beyond normal energy costs and the public was suffering frequent rolling blackouts during power emergencies.

An elaborate test set was constructed at the PG&E San Ramon Technology Center ($90,000). All types of household appliances and commercial equipment were tested for performance under low voltages that could be produced by the mode 1 version of the Load Reduction Switch proposed (see mode 1 and mode 2 LRS descriptions in Appendix I). Even though this effort eventually demonstrated that the mode 1 LRS could not be used in the field, the data collected brought about a realization of much greater importance.

The combined results from these tests showed that customer voltages on the entire California electrical grid could be lowered as much as 5% (in fact, down to at least 110 volts or 220 volts). We realized that this could reduce the load on the state-wide electrical grid enough to avoid the necessity of rolling blackouts during power emergencies -- maybe even more load reduction than what we hoped to accomplish with the Load Reduction Switch. This was called Emergency Voltage Reduction (EVR). It was a major unanticipated discovery of the contract work. But the state paid nothing extra to make this discovery. It came from the extensive test data recorded during the required low voltage testing for the mode 1 Load Reduction Switch evaluation.

The official report from the investigation of the northeast blackout of August 14, 2003, states that immediate moderate load reduction by one utility could have prevented the grid collapse that blacked out a large part of the United States. Executing local blackouts and/or EVR immediately by this utility could have prevented the northeast grid collapse. None of the utilities connected to the northeast gird had prepared or practiced such an emergency plan.

2. **All Appliances and motors performed well at lower voltage**

Laboratory tests showed no adverse effect of low voltages whatsoever on domestic appliances and commercial equipment when the voltage was as low as 100 volts (equivalent 200 volts for "240 volt" equipment). The biggest surprise came from the greatest domestic load on our power grids during summertime. Comprehensive tests showed that the most popular home air conditioners continue to run well at voltages as low as 200 volts. In fact, they are most efficient at around 200 volts, not the standard 240 volts. Their power factor actually increases with lower voltage down to 200 volts. The drop in power output of the air conditioner motors is insignificant from 240 down to 200 volts. But the overall EER energy efficiency ratio (BTU's of heat transferred versus power consumed) actually improves slightly down to 200 volts.

This test data proved that these air conditioners can be run very safely at 220 volts (110 equivalent) instead of 240 volts during power emergencies. We realized that minor voltage reduction could produce a very big power reduction on the gird during peak demand times on hot summer days. Achieving such a power reduction during power emergencies was the whole purpose of the Load Reduction Switch project (this contract). Here was a way to accomplish the same objective at much less cost and much more quickly than installing hundreds of thousands of Load Reduction Switches on homes throughout the state.

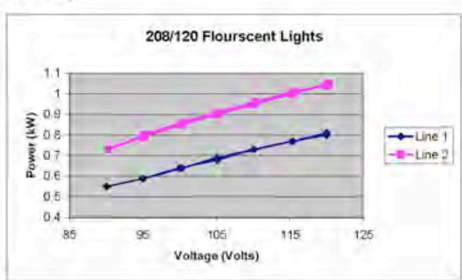
The data tables and graphs below show the power consumed and the power factor for various appliances at different voltages. The appliances were installed on the PGE San Ramon home appliance test set and tested during the Load Reduction Switch project in 2001.

The graph below shows the performance of fluorescent lights at various voltages from 120 volts down to 90 volts. The drop in power demand is almost linear with voltage reduction. The power factor is essentially 1.0 in the range 120 volts down to 105 volts for the lighting units tested.

Flourescent Light Test
120 Volt Ballast
PG&E TES Panel LM (located in High Voltage Dome. inside stairwell / prep room lower door access)

6/5/2001
10:25
69.9 deg F

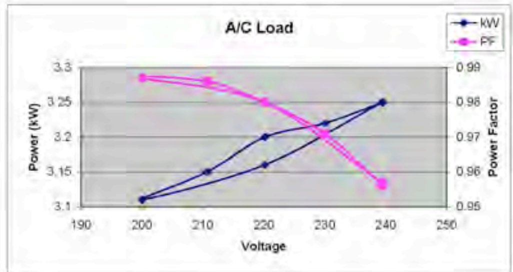
Line 1				Line 2			
V	I	kW	PF	V	I	kW	PF
120	6.7	0.81	1	120.3	8.82	1.05	0.987
115.3	6.6	0.77	1	115.4	8.74	1	0.993
110.1	6.51	0.73	1	110.1	8.66	0.95	0.996
105.1	6.42	0.68	1	105.2	8.59	0.9	0.999
100	6.3	0.64	1	100.2	8.51	0.85	0.995
95	6.17	0.59	1	95	8.41	0.79	0.991
90	6.09	0.55	0.999	90.2	8.28	0.73	0.981
95	6.17	0.59	1	95.2	8.44	0.8	0.989
100.3	6.33	0.64	1	100.2	8.56	0.86	0.996
105.1	6.44	0.69	1	105.1	8.64	0.91	0.998
110.1	6.52	0.73	1	110.3	8.7	0.96	0.998
115.4	6.8	0.77	1	115.5	8.74	1.01	0.996
120	6.64	0.8	1	120	8.78	1.04	0.989



Note: This test was performed on a bank of 3-phase, 208/120-volt flourescent lights located at PG&E's San Ramon Test Facility. These preliminarey test results are for the specific lights that we have installed. Its thought that these lights are typical of lights installed in commercial buildings. However, further investigations need to be performed to ensure that these results can be extended other 208/120-volt light manufacturers and vintages

Loads
A/C

Voltage	Current	kW	PF	kVA
239.5	14.25	3.25	0.956	3.41
230	14.4	3.22	0.971	3.31
220.2	14.71	3.2	0.98	3.24
210.7	15.2	3.15	0.986	3.20
200	15.67	3.11	0.987	3.17
220.1	14.68	3.16	0.98	3.23
239.4	14.2	3.25	0.957	3.40



Note: This test was performed on a typical household furnace/air conditioner at PG&E's San Ramon Test Facility. These preliminarey test results are for the specific furnace/AC that we have installed. While the furnace/AC is typical of a furnace/AC used by residential customers, it by no means covers the full range of furnace/AC units in the typical residence. Further investigations need to be performed to ensure that these results can be extended to other manufacturers and vintages.

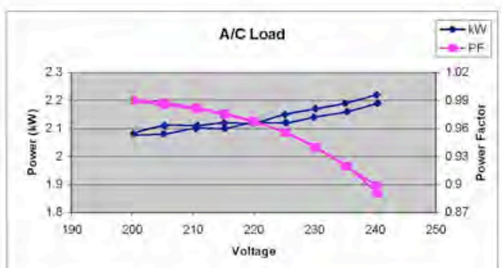
The data table and graph above for a popular modern home air conditioner (3 KW model) tested in 2001 shows the performance of this “240-volt” appliance from 240 volts down to 200 volts. The power factor (pink line) increases as the voltage drops to 200 volts (the energy efficiency of the motor is better at lower voltage). The power consumed in kilowatts (the blue line) decreases as the voltage drops to 200 volts. The power consumed is reduced by 4.5 % at 200 volts compared to operation at 240 volts. At 220 volts the power consumed is still reduced by 3 %. Even at 230 volts there is a 1.5 % power reduction with a 1.5 % improvement in power factor.

The first graph below gives the performance of another popular model of home air conditioner of lower cooling capacity (2 kW model). The power reduction is over 2 % at 230 volts compared to operation at 240 volts. The power factor improvement is 5.5 %. If we go down to 220 volts, the power reduction is over 4 % and the power factor improves by 7%.

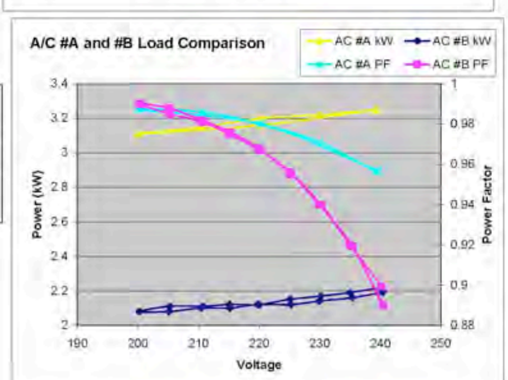
The bottom graph shows the combined data for the two air conditioners tested.

Loads
Trane XL1400

Voltage	Current	kW	PF	kVA
240.4	10.17	2.19	0.89	2.44
235.4	10	2.16	0.919	2.35
229.9	9.88	2.14	0.94	2.27
225.3	9.88	2.12	0.955	2.23
219.8	9.94	2.12	0.968	2.18
215.2	10.01	2.1	0.976	2.15
210.4	10.14	2.1	0.982	2.13
205.1	10.28	2.08	0.988	2.11
200.2	10.47	2.08	0.99	2.10
205.3	10.42	2.11	0.985	2.14
210.7	10.22	2.11	0.981	2.15
215.1	10.11	2.12	0.975	2.17
220.1	10.02	2.12	0.967	2.21
225.1	9.97	2.15	0.956	2.24
230.2	10.02	2.17	0.94	2.31
235	10.09	2.19	0.92	2.37
240.2	10.27	2.22	0.899	2.47



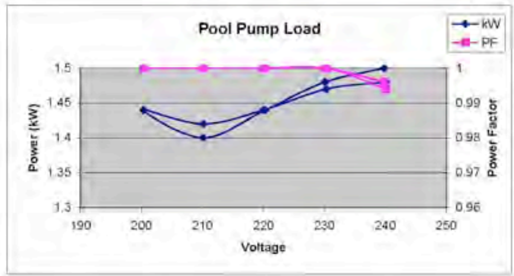
Note: This test was performed on a typical household furnace/air conditioner at PG&E's San Ramon Test Facility. These preliminarey test results are for the specific furnace/AC that we have installed. While the furnace/AC is typical of a furnace/AC used by residential customers, it by no means covers the full range of furnace/AC units in the typical residence. Further investigations need to be performed to ensure that these results can be extended to other manufacturers and vintages.



Loads

Pool Pump

Voltage	Current	kW	PF	kVA	
239.6	6.32	1.5	0.996	1.52	
230.1	6.25	1.48	1	1.44	1
220.3	6.37	1.44	1	1.40	1
210.1	6.61	1.4	1	1.39	1
200.3	6.89	1.44	1	1.36	1
210.1	6.54	1.42	1	1.37	1
220	6.33	1.44	1	1.39	1
230.3	6.25	1.47	1	1.44	1
240.1	6.32	1.48	0.994	1.52	



Note: This test was performed on a typical household pool pump at PG&E's San Ramon Test Facility. These preliminarey test results are for the specific pool pump that we have installed. While the pool pump is typical of a pool pumps used by residential customers, it by no means covers the full range of pool pumps in the typical residence. Further investigations need to be performed to ensure that these results can be extended to other manufacturers and vintages.

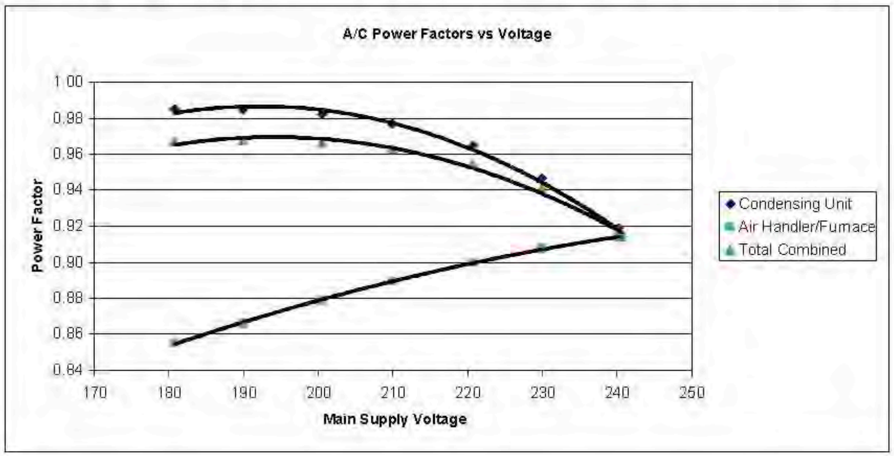
The graph above shows the low voltage performance of a pool pump, a typical 240-volt electric motor. The minimum power demand and the maximum power factor again occur at 210 volts, not 240 volts. Continuous operation of this motor at a lower voltage such as 220 volts presents no problem whatsoever. (This is the equivalent of dropping consumer line voltages to 110 volts from 120 volts).

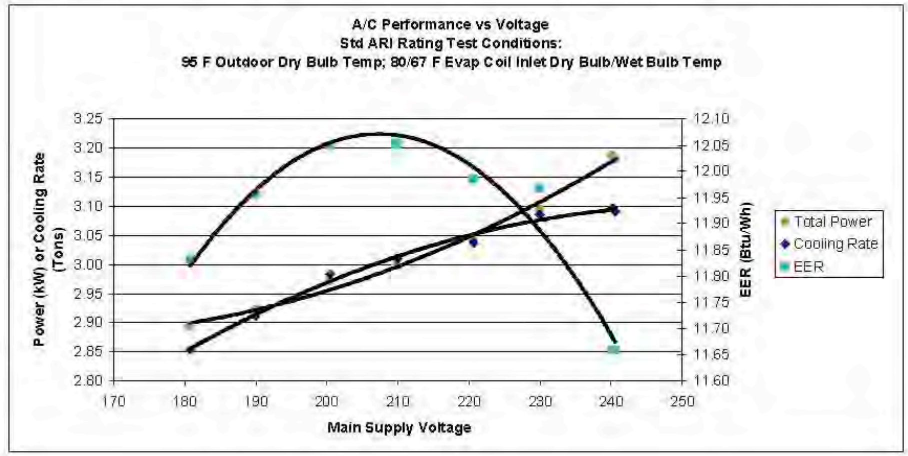
The combined data table and graph on the next page labeled "A/C Performance vs Voltage" show the overall performance and efficiency of a typical modern 3 KW air conditioner unit at voltages from 240 volts down to 180 volts. Note that the voltage at which the maximum EER (overall air conditioner performance factor) occurs is 210 volts, not 240 volts. This means that a tremendous amount of energy is being wasted by operating these air conditioners at the excessively high 240 volts. Air conditioners account for a very large part of the domestic load on the gird during peak demand times when most power emergencies occur. There is no question that a big reduction in the air conditioner demand on a grid can be achieved simply by lowering distribution line voltages a few volts (see calculations made by the ENERGY COMMISSION in various reports and memos in Appendix IV).

Notice that the power demand reduction by operating this air conditioning unit at 230 volts is 2.7%. The saving is 4.4% at 220 volts. And the power saving is 5.8% at 210 volts. The 2.7% power reduction at 230/115 volts is consistent with the 2% overall power reduction seen on distribution lines with 5% voltage reduction from 120 volts on a hot summer day (see Section 3 below).

Performance Test Results for A/C Unit versus voltage

Date	Evap Inlet Air Temp: Dry Bulb	Evap Inlet Air Temp: Wet Bulb	Evap Outlet Air Temp: Dry Bulb	Evap Outlet Air Temp: Wet Bulb	Evap Outlet Static Pressure	Evap Air Flow	Condenser Inlet Air Temp: Dry Bulb	Condenser Inlet Air Temp: Wet Bulb	Cond Air Flow	Compressor / Motor Shell Temp	Condensing Unit Power: Voltage	Condensing Unit Power: Current	Condensing Unit Power: Power	Condensing Unit Power: Power	Condensing Unit Power: Power Factor	Air Handler/Furnace Power: Voltage	Air Handler/Furnace Power: Current	Air Handler/Furnace Power: Power	Air Handler/Furnace Power: Power	Air Handler/Furnace Power: Power Factor	Combined Power: **Power**	Combined Power: kVA	Combined Power: Power Factor	Performance: Cooling Rate	Performance: **EER**
	(ºF)	(ºF)	(ºF)	(ºF)	(IW)	(ACFM)	(ºF)	(ºF)	(ACFM)	(ºF)	**(V)**	(Amps)	(kW)	(kVA)		(V)	(Amps)	(kW)	(kVA)		**(kW)**	(kVA)		(Tons)	**(Btu/Wh)**
07/17/01	80.0	67.0	60.2	57.2	0.326	1,200	95.0	75.6	1,133	117.4	**240.6**	12.18	2.678	2.93	0.914	120.0	4.58	0.502	0.550	0.914	**3.181**	3.480	**0.914**	3.09	**11.66**
07/17/01	80.0	67.1	59.9	57.0	0.296	1,161	95.0	75.3	1,125	116.0	**229.9**	12.00	2.611	2.76	0.947	114.7	4.65	0.484	0.533	0.908	**3.095**	3.291	**0.940**	3.09	**11.97**
07/17/01	80.0	66.7	59.2	56.3	0.273	1,116	95.0	75.5	1,118	114.4	**220.6**	12.11	2.577	2.67	0.965	110.1	4.68	0.464	0.516	0.900	**3.041**	3.186	**0.954**	3.04	**11.99**
07/17/01	80.0	66.9	58.7	56.0	0.243	1,053	95.0	76.0	1,108	114.6	**209.9**	12.49	2.560	2.62	0.977	104.7	4.71	0.438	0.493	0.889	**2.998**	3.114	**0.963**	3.01	**12.05**
07/17/01	80.0	67.2	58.3	55.7	0.214	989	95.0	76.5	1,098	113.8	**200.5**	12.99	2.558	2.60	0.982	100.0	4.70	0.413	0.470	0.879	**2.971**	3.074	**0.966**	2.98	**12.05**
07/17/01	80.0	67.0	57.2	54.7	0.182	911	95.0	76.3	1,065	113.7	**189.9**	13.59	2.542	2.58	0.985	94.8	4.64	0.381	0.440	0.866	**2.922**	3.021	**0.967**	2.91	**11.96**
07/17/01	80.0	67.0	56.3	53.9	0.155	840	95.0	76.3	1,070	114.8	**180.8**	14.27	2.542	2.58	0.985	90.2	4.55	0.351	0.411	0.855	**2.893**	2.991	**0.967**	2.85	**11.83**
07/18/01	80.0	67.0	60.0	57.3	0.322	1,200	95.1	75.8	1,087	113.3	**240.2**	12.17	2.684	2.92	0.919	120.0	4.59	0.503	0.551	0.914	**3.188**	3.473	**0.918**	3.10	**11.66**





Note: This air-conditioning (A/C) unit was tested in PG&E's A/C performance test facility in San Ramon. Performance tests had just been completed on this unit as part of PG&E's customer energy efficiency programs, so it was left in place for this voltage reduction test. Although this unit had a standard residential size compressor, and a standard residential air handler/furnace unit, the condense was not typical. This unit had a water-cooled condenser, where-as most residential units have an air-cooled condenser. Although th absolute values for the energy efficiency ratio (EER) may be different than typical units, the trend in performance due to voltage changes should be similiar since the compressor and furnace unit was typical. However, there are many different types of air conditioning units available, and further investigations would be needed to ensure that these results can be extended to other manufacturers and vintages. Also, A/C unit performance is very dependent on outside temperature, and evaporator coil inlet dry and wet bulb temperatures. These tests were performed holding these parameters constant at standard ARI (Air-conditioning and Refrigeration Institute) rating conditions. Results may vary at different operating conditions.

3. Enormous energy waste on the grid at present high voltages. Experiments on loaded distribution lines prove that EVR can reduce demand quickly to avoid blackouts or grid collapse.

The data tables and graphs above demonstrate what can be saved by reducing utility line voltages during peak demand times. But the story is better than that. The same is true for the total consumer load on an electrical grid. The laboratory test data (not shown) showed that the overall reduction in power demand from all electrical loads during peak demand times is about 0.4% for each 1 volt reduction below 120/240 volts (down to 105 volts). **This is a 2% instant reduction of load on the grid for a 5% reduction in line voltage (see 6-16-01 memos from Rosenfeld and Wattenburg in section 4 below). But the real proof came from actual field tests done on fully loaded utility distribution lines during peak demand times. These field tests showed the same overall load reduction as measured on the laboratory test set.**

To verify our predictions from the laboratory test data, the ENERGY COMMISSION asked Southern California Edison (SCE) company to do experiments on their own distribution lines in early June 2001. SCE lowered voltages 5% on fully loaded distribution lines serving hundreds of thousands of customers in central Los Angles at a peak demand time for several hours. They measured the predicted power demand reduction of 2% for a 5% voltage drop. There were no customer complaints.

(SCE did experience a strange jump in line current during the first test, but this was because the capacitors on their distribution lines over-compensated when the voltage was lowered. The capacitors were disconnected in the next experiment and there was no increase in line current along with the power demand reduction.)

This means that an enormous amount of energy is being wasted on our power grids during peak demand times. (actually all the time that most modern non-resistive appliances are operated above 110 volts). It also proves that utilities can use Emergency Voltage Reduction (EVR) to reduce the load on an electrical grid immediately during power emergencies to avoid blackouts -- or better yet, to avoid collapse of the entire grid as happened in the northeast in August 2004.

The California peak demand in 2004 was over 43,000 megawatts. A 5% voltage reduction will produce a 2% reduction in demand wherever it is used. This is a potential 860 megawatts in California. This much load reduction can be achieved by emergency voltage reduction (EVR) alone. No blackouts required. No customer knows the difference. 860 megawatts is the equivalent of one modern large power plant connected to the grid. In other words, the loss of a major power plant at peak demand time can be made up by instant small voltage reduction on utility distribution lines alone.

A 5% emergency voltage reduction from 120 volts brings utility line voltage down to 114 volts. This is still well above the 110 volts minimum set by the National Standards Association (ANSI) for emergency situations. **There are no appliances or industrial motors sold and used in the U.S. that do not perform perfectly well, and usually more efficiently, at 114 volts (228 volts for 240-volt appliances). And they will only have to operate at this lower voltage for a few hours at most if EVR is used during power emergencies to avoid blackouts or total grid collapse!** (The only thing that customers will notice at 114 volts is that their power bills will go down slightly because their equipment is operating more efficiently and their power meters do not spin as fast as at 120 volts. But the utilities don't like customers to learn this.)

A point of information: The utilities gain some increased margin of safety -- a cushion of sorts -- by keeping voltage in the 120-125 range instead of the old 115 volt range (which was 110 volts before that). If they lose a distribution line that causes a drop in voltage on other lines, then their customers on the other lines likely will not drop below 110 volts. For this reason, the principal investigator supported the request by the utilities' to increase customer voltage in the 1970's before the California PUC.

4. Correspondence on The Planning for Emergency Voltage Reduction between the California Energy Commission, the Principal Investigator, and the Governor's Office, June – July 2001

It all began here:

6/16/01

To: Voltage Reduction List
All California Utilities

From: Art Rosenfeld

Next Conference Call: 10 am Tue. 6-19, from Governor's office: call in #916-227-6423

This is to urge you to be prepared to come up with a proposal for your individual utility.

I hope you've all received the nice PG&E data which Greg Starnes e-mailed our whole list.

I’m attaching an e-mail from Joseph Wrubel, recently retired from PSEG, saying that PJM has reduced voltage 3-5% and sees power drops of 1-2%..

I’ve looked at a few motor manuals, and conclude that motors are designed for 115 +/- 11.5 volts, so are designed to work down to 103.5 v (or 207, …). I think we agreed that we should aim for more like 110 volts at the sagging end of each feeder, and need to know what that calls for at the its supply end. I hope you are measuring the distribution of these sagged voltages, and making an allowance for hotter weather. I’m very interested in the notion that we should plan an individual supply-end voltage for each feeder.

I remember that SCE, with good communications, may want to propose lowering the voltage half way for the whole summer, and the rest of the way during an emergency.
PG&E, with worse communications, probably can’t address individual emergencies.

I’ve checked the conference call time with Kurt Schuparra (Gov.) and with Bob Kinosian (CPUC), and I assume that at least one person from each utility, plus Wattenburg, can call in. If any really bad conflict, let me know pronto.

(end Rosenfeld memo)

June 16, 2001

To: Dr. Art Rosenfeld, Kurt Schuparra
From: Dr. Bill Wattenburg

Subject: Voltage Reduction Plan

I think we need to discuss privately how the governor’s office can best use this energy savings to play the poker game with power suppliers. I can tell you for certain that anything we say in a conference call or that is known to the ISO and CPUC people will be known to the power suppliers very soon. The power suppliers have been able to look at the state’s poker hand while the state has been negotiating with them . That is no way to play poker if you have the cards to do some heavy bluffing at the right time. We can give the governor a couple of aces to use at the best time -- 500 to 1000 megawatts of power in his pocket to use at the best times.

SCE ran some more tests on their substations last Friday as they had promised. They essentially verified the load reduction possible as we had projected based on the tests that the CEC/PGE engineering team and I have done this last month. They corrected the problem with the capacitors on the lines as I suggested and found that the "20% increase in line current" was caused by the capacitors overreacting as I had told them. They disconnected the capacitors and got about a 2% load reduction for a 5% drop in voltage – as projected (0.4% power drop for each 1 volt reduction in line voltage). This is all we need.

As of Friday, PG&E was still "writing a test plan" as I suspected they would from the comments that one middle manager made during our last conference call. Their best technical people know the answer, but they have to go along with the guy who was wringing his hands and worrying about possible "customer complaints" over lower voltages (which do not exist unless you tell them the voltage has been lowered). By the time they finish a "test plan" the world will know about it and the so-called consumer groups will be preparing complaints to get into the act in some way.

My analysis of the test data we have so far says that we may get more mileage out of this by reducing voltages, say, 3% across the board for the summer and saving some of the additional reduction. But we can't continue telling the other side what cards we do and do not have in our hand.

(end Wattenburg memo)

---

5. ENERGY COMMISSION Recommends EVR to the Governor

In the following memo dated June 22, 2001, Commissioner Arthur Rosenfeld of the California Energy Commission recommended to the governor of California that utility voltages should be lowered by 2 ½ % (but no lower than 117 volts) during power emergencies. This could lower overall energy demand and avoid rolling blackouts in the state.

To Kurt Schuparra, Governor's Office

From Art Rosenfeld (w/ Wattenburg's comments incorporated)
22 June '01

Governor Davis asks CPUC to order utilities to reduce voltage this summer and thus drop state power demand by 500 MW.

Governor Davis could add something like this:

This is energy savings in which all will share to complement the great conservation contribution from the general public. Extensive engineering

tests have confirmed that most customers will barely notice the difference if voltages are lowered to historical levels-- except that their power bills will be slightly lower.

BACKGROUND

A series of interesting measurements and productive conference calls have evolved a strategy to reduce electricity demand by 1% to 1.5% (500 MW or more) by harmlessly dropping voltage 2.5 % at utility substations and transformers. 500 MW represents a modern power plant.

Voltage reduction of 3-5% during emergencies is a common strategy in many states. In California during earlier shortages, following the 1973 OPEC oil embargo, power was normally supplied at 110 volts (or some multiple thereof for commercial customers), and was dropped 3-6% causing a 1-2% drop in "load."

But later, in the '80s, shortage turned to excess which resulted in an event, and a non-event, which make voltage reduction more interesting today. The event was that the utilities, with CPUC permission, raised the supply voltage from 110 to 120 volts. This raised electricity sales but made the system slightly more reliable. The non-event was that motor manufacturers continued to design motors to operate best from 105 to 120 volts, so that they could continue to sell in areas , where voltage often sags well below 110 volts.

California Energy Commissioner Arthur H. Rosenfeld assembled a team of engineers and scientists to investigate several ways to avoid rotating blackouts. The team is led by Dr. Bill Wattenburg, consultant to LLNL (Lawrence Livermore Nat. Lab.) and includes top engineers from PG&E, SCE, and SDG&E. For the past two months, they have been working at the PG&E Technical Center in San Ramon where they have assembled extensive test facilities for measuring utility load reduction procedures.

Wattenburg initiated tests of a 10-volt drop on typical homes and commercial equipment (a drop 3 times larger than the team currently recommends) with the following results. Overall, the power demand (the "load") dropped 3%-5% with no danger whatsoever to home appliances or commercial equipment. Indeed, the engineering team discovered that all home appliances and most commercial equipment operated more efficiently at 110 volts than it does at 120 volts.

Power for “resistive" loads (mainly incandescent lamps, water heaters, electric stoves, etc) dropped 20% (good), so lights dim slightly (but bulbs last longer) , dryers take 20% longer to dry; ovens take 20% longer to reach their thermostat temperature, etc.

Fluorescent lamps draw 10% less power, and dim slightly (good).

Most important are motors, which draw 70% of all power. Their power consumption drops 1%-3%, but their efficiency (power factor) improves. So air conditioners, fans, pumps, etc., become more efficient and run cooler (last longer).
Industrial motors, if speed is critical, are now mainly electronically controlled, and are not affected.

*Electronics (TV, computers, *) have stabilized electronic power supplies, so they "don't care*."

Given these results, corroborated by substation tests at each utility, the utility engineers on the team now feel that they can drop voltage "during emergencies." The problem is that only some of the power companies (like SCE) have electronic control over their substations and transformers where the voltage must be dropped. Most utilities must do it by hand, and PG&E for example, must adjust 2400 substation transformers --- impossible for each emergency. So, they suggested, just drop the voltage all summer. Specifically the team recommends dropping the voltage by 3 volts to 117 v. This should drop load by 1% to 1.5% and still keep customers above the 114 v presently required by the CPUC, despite any voltage sag on the lines between the substations and the customers. One percent of California power corresponds to 500 MW.

The CPUC controls only the 3 large Investor-Owned Utilities, and is expected soon to order them to make the 3 volt reduction. Hopefully utilities with electronic voltage control will consider going even further during emergencies. One quarter of California power is delivered by municipal utilities, who are independent of the CPUC, but are also studying this new strategy.

Art Rosenfeld, Commissioner
California Energy Commission
1516 9th St.,Sac'to CA, 95814
(916)654-4930, fax 653-3478
Cell-phone (telephone number deleted)
Arosenfe@energy.state.ca.us
www.energy.ca.gov

(end memo from Art Rosenfeld)

During conference calls with utility representatives in June 2001 to plan for using EVR (arranged by the governor's office), the argument was made to the utilities that in return for keeping voltages at the 120 level all the time for reliability reasons the utilities should be willing to drop voltage to the very safe and adequate 115 - 117 volt range for a few hours during power emergencies instead of forcing blackouts or risking grid collapse. Senior engineering representatives from PG&E, SCE, and SDG&E agreed at the time. Initially, each of the three utilities promised to contribute a certain amount of load reduction by EVR that, collectively, would amount to over 250 megawatts of load reduction. It was agreed that much greater power reduction (up to 500 megawatts) could be achieved with EVR. However, the utilities said they needed time to plan for it and they needed protective regulation from the California Public Utilities Commission. PGE representatives even suggested that they could bring down the voltage on their distribution lines for the entire summer rather than just drop voltage during the expected power emergencies in the summer of 2001.

The governor issued a press release and organized a state-wide conference call to the media on July 3, 2001, to announce that he would ask the California Public Utilities Commission (PUC) to order the utilities to use EVR during future power emergencies (see page 1).

The California energy crisis came to an end on July 7, 2001. The price of power came down to reasonable levels. There were no more power emergencies during the summer of 2001 (all the "power experts" had been predicting frequent rolling blackouts throughout the summer of 2001 in news stories almost every day for the previous three months).

6. Utilities Oppose Emergency Voltage Reduction

The California Public Utilities Commission (PUC) began a hearing on October 5, 2001, on the governor's July 2001 request that the utilities use EVR during power emergencies (CPUC Rule Making R. 00-10-002 Filed October 5, 2001). This was well after the California energy crisis was over.

The same utilities that had agreed to use EVR in June 2001, fought fiercely before the California PUC to kill the governor's EVR proposal that voltages be dropped by at least 2 1/2 % during emergencies to avoid blackouts or grid collapse in the future. In sworn and documented testimony, a parade of utility executives and representatives used the argument that the utilities would be sued by customers with "sensitive equipment" that could be harmed by lowering voltage to 117 volts. (But they could not describe a single piece of such "sensitive equipment.") They also testified that industrial motors might draw excessive current at lower voltages. They did not tell the PUC commissioner that the motor manufacturers own specification sheets show that all motors on the market today operate more efficiently at 210 to 220 volts than 240 volts, with only a very slight drop in power output. This is equivalent to 105 to 110 volts on "120 volt circuits." The regulation requested by the governor only asked for voltage reduction to 117 volts at the least.

The principle investigator testified (see Section 9 below) and gave the hearing officer the low voltage test data from the Load Reduction Switch project presented herein. He also testified that, on his own time, he had tested a wide range of industrial motors to verify that the motors actually run better and cooler at the voltages much lower than those requested for EVR (this had to be done on weekends when factories were idle.) Still, "expert witnesses" offered by the utilities insisted that damage could be done by lowering voltages even 2 ½ % for short periods of time during emergencies (transcripts of PUC hearings, October 2001). **What is curious about this "expert testimony" is that swings in power demand on the electrical grid often lower line voltages more than 2 ½ % during normal times.**

For two months, the utility and power company lawyers fought the emergency voltage reduction proposal before California Public Utilities Commission with an army of "expert" witnesses from all the utilities and power companies. ENERGY COMMISSION Commissioner Rosenfeld suggested that the principle investigator (the only one representing the ENERGY COMMISSION and the governor's office at this PUC hearing) not spend a great deal of effort challenging the utility testimony because the energy crisis was over for the time being.

In November 2001, the PUC hearing officer eventually ruled against the governor's request that EVR be used during future power emergencies

7. Why Utilities and Power Companies Don't Like EVR

The memo below to the governor's office in June 2001 contains the opinions and suggestions offered by the principal investigator on how and why the utilities and power providers do not like EVR and how to deal with the power providers during the California energy crisis. These opinions were solicited by the governor's staff. The events of the summer of 2001 did not prove them to be wrong.

June 23, 2001

To: Dr. Art Rosenfeld, Commissioner ENERGY COMMISSION
Kurt Schuparra, Governor's Office
From: Dr. Bill Wattenburg
Subject: The Power Producers Game Plan for California

My sources within the private power producers tell me that they plan to be on their good behavior and ready to supply all the power they are capable of producing at any time during this summer. Then they will wait until demand exceeds maximum available supply and they can prove that their hands are clean when the blackouts come. They are surprised about the amount that the public has conserved, but they know this is only temporary until the sense of crisis passes. Then the demand will return.

However, they are very unhappy about what we are planning with voltage reduction. They are getting a lot of heat from the power and utility industry organizations because voltage reduction could be used by other states across the country if it is done in California. They know that a

drop of no more than 5% from 120 volts nominal makes no difference to customers. They don't want the general public and state PUC agencies around the country to learn for sure that voltages can be reduced easily and safely. They don't want an outcry from the general public and the media who could believe that voltages have been kept unnecessarily high – even during the past horribly expensive crises -- just to increase utility profits (true to some extent).

This is why even 500 megawatts of load reduction by voltage reduction can give us both a safety factor and leverage over the power producers. The last thing they will want us to do is reduce another 2 ½ % during a peak emergency to avoid a blackout. They will have a big vested interest to keep us out of peak emergencies if we prove to them that we are going to reduce voltages by 2 ½ % now – and we can do more if they force us.

I think the last few weeks have been evidence that they are trying to show that their hands are clean. My sources tell me that they are doing more maintenance at night just to be sure they are available during any peak demand during the day. But this is no time to let our guard down. We must keep their backs to the wall by any means we can.

(end memo from Bill Wattenburg)

---

8. Latest proposals to the ENERGY COMMISSION to plan for using EVR during power emergencies with supporting data:

Abstract of an April 2004 Proposal to the California Energy Commission to Develop an Emergency Voltage Reduction Plan to Prevent a Collapse of the West Coast Electrical Grid. This proposal was made to the California Energy Commission PIER staff shortly after the issuance of the official report on the causes of the northeast blackout on August 14, 2003.

By Dr. Bill Wattenburg

April 5, 2004

The purpose of this project is to develop an emergency response plan that will prevent collapse of the west coast electrical grid as happened with the northeast grid on August 14, 2004. The major emergency response procedure to be investigated is wide-area voltage reduction (VR). VR can rapidly decrease the demand load on the grid so that power plants and transmission lines will not automatically disconnect and cause ripple-effect collapse of the grid.

Overcoming power industry and utility arguments against emergency voltage reduction will require proving that all customer appliances and commercial equipment operate very well at 110 to 115 volt levels (220 to 230 volt equivalent) with no danger or damage to the equipment --- certainly for short periods of time to decrease an overload on the grid. Laboratory and field tests of appliances and commercial equipment operated at low voltage will be done in a fashion and over a long enough period of time (many months of continuous operation) that the results cannot be discounted by so-called experts who conjure up fears of equipment failure with the slightest reduction of voltage, even though our previous extensive tests at the PG&E lab and manufacturer's specifications say otherwise. PG&E will not allow us to publish the data taken at their lab in 2001. Hence, we must redo these tests to verify the 2001 results.

To the extent necessary, customer voltages around the state will be monitored for at least a year to determine where and when voltage levels can be safely lowered during emergencies.

When deemed appropriate by the CEC, emergency response procedures to prevent grid collapse will be proposed to utilities and power providers.

The above proposal was followed up by a report and request to Commissioner Rosenfeld with full supporting data:

6-5-04

To: Art Rosenfeld:
Arosenfe@energy.state.ca.us

Subject: Enorrmous Load Reduction and Energy Savings With Harmless Voltage Reduct ion

Copy: rlg2@us.ibm.com, rgarwin@cfr.org

I am attaching an EXCELL file that contains the very revealing test data on modern air conditioners that we discussed yesterday. I finally put all the essential parameters measured on one page. These tests were done in the most comprehensive test facitlity available for measuring combined performace of Air Conditioning units.
The load reduction from 240 volts down to 210 volts is outrageous -- 5.8 percent power reduction, increased Btu/Wh and actual improved performance of the AC unit main motor and compressor.

You have to look at this. Let's stop kidding ourselves. Air Conditioners nationally are the biggest factor in peak demand on our power systems and the biggest threat to grid collapse when there are transmission line or power plant outages.
I don't think you have seen the complete data summar zed as it is here. The EXCELL page entitled Sheet 1 is wider than the computer screen. You must use the scrolling tabs on the bottom and right side of the window to see all the data tables at the top. Scroll over to the last column and see what is there. I have put the main tables in bold type.

Here is a bigger load reduction potential (5.8 percent) during peak times than all other secondary load reduction strategies put together. And yet, over a 100 million dollars of PIER money has been spent over the last three years alone by those who do nothing more than wave their arms and speculate on the common "energy expert" busswords and urban myths that have been of no value to the quality or price of power to the public.

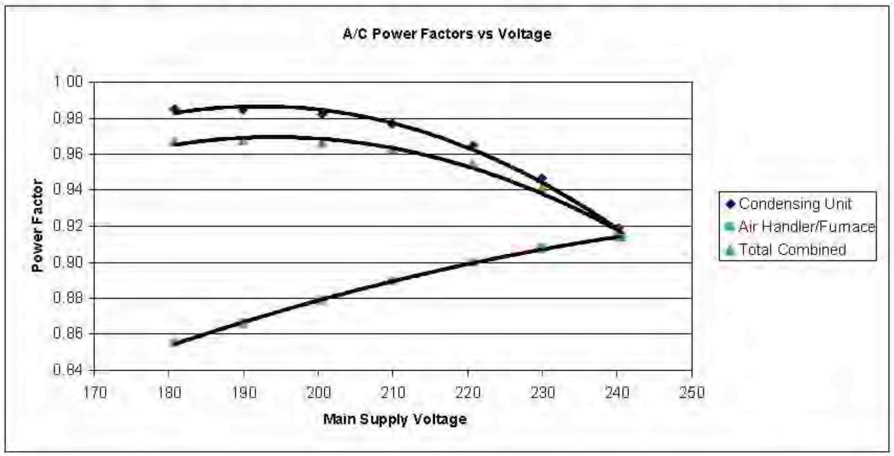
Art, look at the outrageous difference between the overall performance (BTU/Wh) of modern AC units at as low as 200 volts compared to the 240 volts they are being given now (5.8 percent power reduction with improved performance of the motors and compressors).
The best performance using the least power is between 200 and 209.9 (210) volts. This means that we can easily drop to service voltages to 110 volts equivalent (220) and still have a cushion of another 10 volts drop before there is any degradation of performance for the A/C units. And you know that our previous studies showed that all other household and commercial appliances and motors performed better at 110 (220) than at 120 (240) bolts.

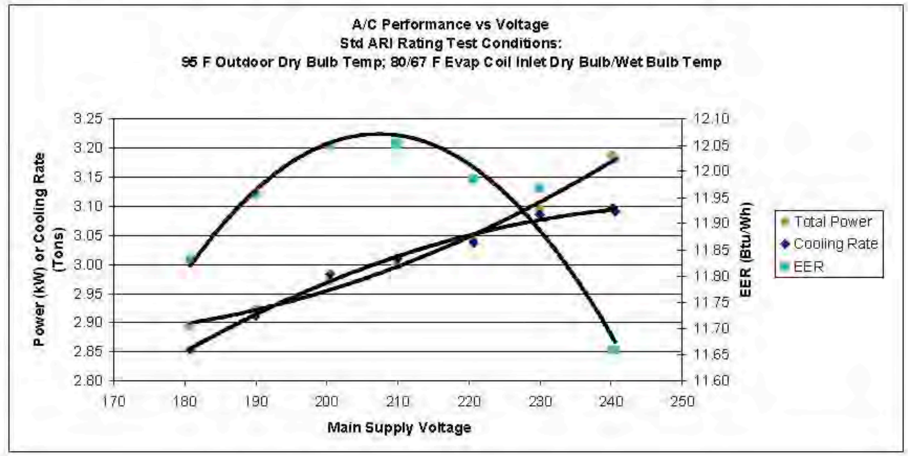
Every parameter improves with voltage drop. Look at the compressor/motor shell temperature, for instance. This is a major wear factor in electrical motors and compressors, and a measure of wasted heat, obviously. There is a 3 degree drop from 117 to 114 degrees for a voltage drop from 240 to 209.9. This translates directly into slighly longer life for the equipment, no the opposite as the the naive power equipment experts speculate.

It is interesting the jounals such as Science and Nature will devote ten pages to the consequences and handwringing over a major grid collapse such as the northeast collapse of August 14, 2003, yet they show no interest in publishing hard data on the causes and very real cures that could be explored.

Performance Test Results for A/C Unit versus voltage

	Evap Inlet Air Temp		Evap Outlet Air Temp		Evap Outlet Static Pressure	Evap Air Flow	Condenser Inlet Air Temp		Cond Air Flow	Compressor / Motor Shell Temp	Condensing Unit Power					Air Handler/Furnace Power					Combined Power			Performance	
Date	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb			Dry Bulb	Wet Bulb			Voltage	Current	Power		Power Factor	Voltage	Current	Power		Power Factor	**Power**	kVA	Power Factor	Cooling Rate	**EER**
	(ºF)	(ºF)	(ºF)	(ºF)	(IW)	(ACFM)	(ºF)	(ºF)	(ACFM)	(ºF)	**(V)**	(Amps)	(kW)	(kVA)		(V)	(Amps)	(kW)	(kVA)		**(kW)**	(kVA)		(Tons)	**(Btu/Wh)**
07/17/01	80.0	67.0	60.2	57.2	0.326	1,200	95.0	75.6	1,133	117.4	**240.6**	12.18	2.678	2.93	0.914	120.0	4.58	0.502	0.550	0.914	**3.181**	3.480	**0.914**	3.09	**11.66**
07/17/01	80.0	67.1	59.9	57.0	0.296	1,161	95.0	75.3	1,125	116.0	**229.9**	12.00	2.611	2.76	0.947	114.7	4.65	0.484	0.533	0.908	**3.095**	3.291	**0.940**	3.09	**11.97**
07/17/01	80.0	66.7	59.2	56.3	0.273	1,116	95.0	75.5	1,118	114.4	**220.6**	12.11	2.577	2.67	0.965	110.1	4.68	0.464	0.516	0.900	**3.041**	3.186	**0.954**	3.04	**11.99**
07/17/01	80.0	66.9	58.7	56.0	0.243	1,053	95.0	76.0	1,108	114.6	**209.9**	12.49	2.560	2.62	0.977	104.7	4.71	0.438	0.493	0.889	**2.998**	3.114	**0.963**	3.01	**12.05**
07/17/01	80.0	67.2	58.3	55.7	0.214	989	95.0	76.5	1,098	113.8	**200.5**	12.99	2.558	2.60	0.982	100.0	4.70	0.413	0.470	0.879	**2.971**	3.074	**0.966**	2.98	**12.05**
07/17/01	80.0	67.0	57.2	54.7	0.182	911	95.0	76.3	1,085	113.7	**189.9**	13.59	2.542	2.58	0.985	94.8	4.64	0.381	0.440	0.866	**2.922**	3.021	**0.967**	2.91	**11.96**
07/17/01	80.0	67.0	56.3	53.9	0.155	840	95.0	76.3	1,070	114.8	**180.8**	14.27	2.542	2.58	0.985	90.2	4.55	0.351	0.411	0.855	**2.893**	2.991	**0.967**	2.85	**11.83**
07/18/01	80.0	67.0	60.0	57.3	0.322	1,200	95.1	75.8	1,087	113.3	**240.2**	12.17	2.684	2.92	0.919	120.0	4.59	0.503	0.551	0.914	**3.188**	3.473	**0.918**	3.10	**11.66**



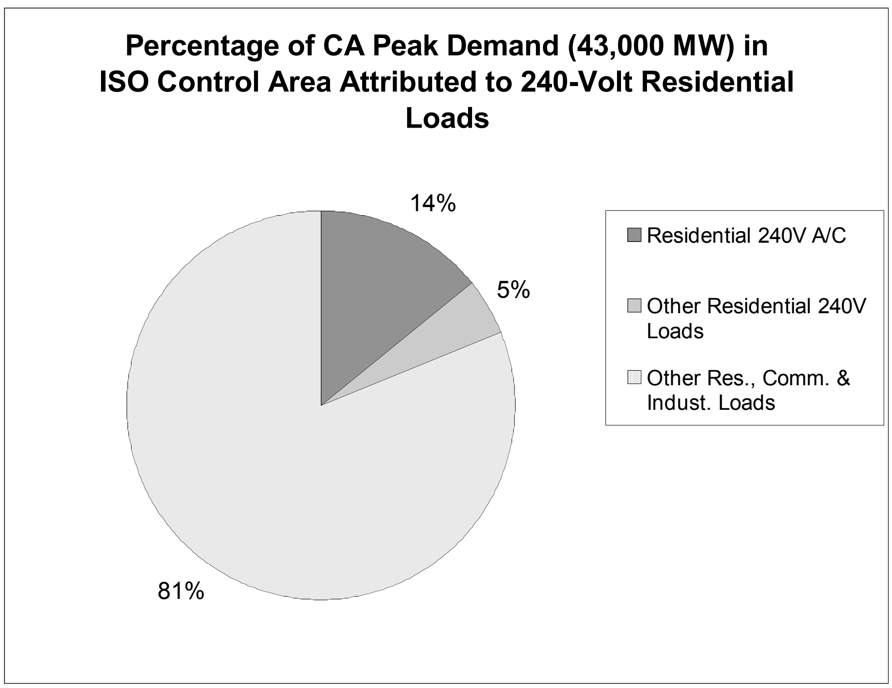


Note: This air-conditioning (A/C) unit was tested in PG&E's A/C performance test facility in San Ramon. Performance tests had just been completed on this unit as part of PG&E's customer energy efficiency programs, so it was left in place for this voltage reduction test. Although this unit had a standard residential size compressor, and a standard residential air handler/furnace unit, the condense was not typical. This unit had a water-cooled condenser, where-as most residential units have an air-cooled condenser. Although th absolute values for the energy efficiency ratio (EER) may be different than typical units, the trend in performance due to voltage changes should be similiar since the compressor and furnace unit was typical. However, there are many different types of air conditioning units available, and further investigations would be needed to ensure that these results can be extended to other manufacturers and vintages. Also, A/C unit performance is very dependent on outside temperature, and evaporator coil inlet dry and wet bulb temperatures. These tests were performed holding these parameters constant at standard ARI (Air-conditioning and Refrigeration Institute) rating conditions. Results may vary at different operating conditions.

In the graph above labeled "A/C Performance vs Voltage," note that the voltage at which the maximum EER (overall air conditioner performance factor) occurs is 210 volts, not 240 volts. This means that a tremendous amount of energy is being wasted by operating millions of air conditioners at the excessively high 240 volts. Air conditioners account for a very large part of the domestic load on the gird during peak demand times when most power emergencies occur. There is no question that a big reduction in the air conditioner demand on a grid can be achieved simply by lowering distribution line voltages a few volts.

We should prepare plans to use voltage Reduction instead of rolling Blackouts during power emergencies.

Approximately 14 % of the 2004 California peak demand of 43,000 megawatts is consumed by 240-volt air conditioners. This is 6020 megawatts. This demand can be reduced instantly by 1.5 % by just reducing distribution line voltages down to a perfectly adequate 115 volts (230 volts equivalent). This



provides 90 megawatts of load reduction from air conditioners alone. **If line voltages are reduced to 110/220 volts, the air conditioner load reduction will be over 5%. This provides a load reduction of over 300 megawatts from air conditioners alone in California. 300 megawatts is more demand reduction than was accomplished with most rolling blackouts in 2001.**

We must be prepared to respond to the next power emergency in California. If not, it could take down the California grid the way the northeast was blacked out in August 2004.

Both of the emergency planning proposals above were rejected by the California Energy Commission PIER staff in 2004 as being "inappropriate" for PIER funding.

9. Public and published documents, test data, and CPUC testimony on emergency voltage reduction

9.1. The principal investigator was asked ENERGY COMMISSION Commissioner Rosenfeld to write the following report after the first conference call between the ENERGY COMMISSION, utility representatives, and the governor's office on the possibility of using EVR to replace the rolling blackouts expected in the summer of 2001.

Voltage Reduction
On Distribution Lines

Bill Wattenburg
June 11, 2001

Comments.

Governor's Order for Rewards to Businesses for Reduction.
Probable Reason for 20% current increase seen by SCE.
The Myth of Motors Failing on Lower Voltage/Higher Current.
Help from PUC on Customer Complaints.

During the conference call with the governor's office on June 7 it was very gratifying to hear that all the California utilities were willing to conduct tests as soon as possible. Again, I want to emphasize that I would be the last one to suggest voltage reduction below the 120 volt standard if we were in the perfect world of adequate energy supply, ample reserves, and reasonable cost. I supported higher line voltages long ago because it clearly provides a more stable and reliable power grid that is capable of absorbing outages and load variability. However, the energy situation today is not the ideal. The most drastic thing we can do to conserve energy must be compared with the consequences of blackouts and bankruptcy.

First of all, the fear of excessive current increases in motors and appliances for small reductions in line voltage (<8%) is totally unrealistic. However, such dire predictions commonly come from service people who heard it from someone else and others who never learned or tested the basics. For high voltage motors (120 and up) at constant load, the percentage current increase is much smaller than the percentage voltage decrease for small voltage reductions in all cases. Since the power consumed usually drops slightly, there is less stress on the motor. This is discussed with test results and examples below.

<u>**Governor's Order for Businesses Rebates**</u>

A lot of businesses and commercial complexes could take advantage of voltage reduction immediately on their own to achieve substantial savings under this plan. Many have main service transformers with voltage control. Plant engineers can adjust their own voltage regulators or reset the taps on their transformers to drop voltage within their installations.

Previous Tests

Unofficial voltage reduction tests have been conducted by many across the country at various times, but none to my knowledge have followed up with long term tests (many weeks at reduced voltage while loads ranged from minimum to maximum). The most recent short-term tests indicate power reductions of 0.4 to 0.6 percent for each one volt reduction below 120 volts equivalent on distribution lines with an average mix of residential and industrial loads. These numbers have been reported for the range of 120 down to 112 volts.

It has been surprising to many that the grid power factor typically increased slightly (like 2 percent). This is because the power consumed and delivered by most motors decreases slightly with voltage but their power factor increases slightly. Line currents increase far less than the percentage voltage reduction (as explained for motors below). The current supplied to resistive loads, of course, decreases linearly with voltage but motors attempt to compensate for reduced voltage by increasing current.

What is important here is that large increases in substation line current should not occur unless capacitor banks overcorrect for reduction of voltage, reduction of power, and power factor improvement. Patrick Lee of SDG&E has also pointed out that the capacitors can overcorrect and produce large leading currents on the lines.

SCE reported a 20% increase in line current for the quick test that they did last week. The conference call was not the place to try to diagnose this curious observation, and I am sure that SCE engineers have probably figured it out by now. However, I was sure that this was very likely caused by capacitor banks that overcorrected for the voltage drop and the attendant frequency and power factor fluctuations on the distribution side. The capacitor banks will have to be reprogrammed or selectively disconnected to balance the power factor with voltage reduction in order to make any careful measurements of power reduction, line currents, and power factor with voltage reduction.

Recent Tests

The substation voltage reduction numbers so far are consistent with the tests we have done at the PG&E tech center at San Ramon for a typical combination of residential loads, appliances, fluorescent lights, and 240 volt motors. The graphical results of these tests have been sent to all of you by Greg Starnes from PG&E Tech Center.

You might note in particular the response of air conditioner 240 motors. A typical one is shown in the graph labeled A/C which was sent to you. The most efficient voltage is in the 210 to 220 range. The real power consumed by the motor drops only 1.5% while the power factor increases about 2.5%. The 8% voltage drop from 239.5 to 220.2 volts produces only a 3.2% current increase when the motor compensates. (Note that, contrary to a lot of technician myths, the percentage increase in current is far less than the percentage decrease in voltage for the same power output. This is true of all high voltage motors when the voltage is varied a small percent around the nominal operating voltage.)

The only way to really analyze what is happening to a motor is to start with its most efficient operating voltage and power output and look at changes above and below that point. In general, increasing the voltage on a motor above its most efficient operating voltage only wastes power and subjects the motor to additional mechanical and electrical stress. Motor failure rates go up with excessively high voltage just as failure rates go up with excessively low voltage and high current (why beyond nominal values).

Consider the A/C motor in the voltage reduction graphs sent. In the most efficient range of 210 to 220, 220 volts is minimum for the grid. The power factor drops as the voltage goes up to 239.9 volts from 220.2 volts. This tells you what is happening. The motor draws an additional 173 volt-amperes, but only 86 watts of real power – which is the maximum it can deliver to its load. The other 87 volt-amperes just drops the power factor and increases the line losses on the grid.

I have done preliminary tests on 480 volt 3-phase industrial motors. The results are about the same across the board when voltage is dropped to 440. These tests should be done for longer periods because I was only able to reduce voltage at industrial sites for a few minutes in a rather crude manner.

The important point here for peak load reduction and operating efficiency on the distribution grid is that the power factor of air conditioner loads and industrial motors is increased by small voltage reduction below the 120/240/480 volt standard. The actual power consumed by the motors and delivered to loads will drop very little with no danger to the motors because they are only moving to a more efficient operating voltage. The power taken by all other resistive and lighting loads drop substantially to provide the nominal overall 0.5% load reduction per volt drop from 120/240/480.

Existing conservation programs can be augmented by voltage reduction. For instance, voltage reduction during peak demand could produce as much additional load reduction as the excellent air conditioner cycling program at Southern California Edison. The two together could double the load reduction possible during peak demand.

Motor and Appliance Failure Myths

Armies of service people repeat the mantra that lower voltages and higher currents are always bad for motors and appliances. This gives them something to tell the customer that sounds smart. This is nonsense when the voltage and current swings are small changes around the most efficient operating point. In this case, reduced voltage actually reduces both the mechanical and electrical stress on the equipment.

In general, the wear and failure rates of equipment of all types increase with the power they are forced to consume or transfer. Far more good motors fail because of voltage spikes than fail because of continuous, moderate increases in current in their windings. When power is held constant, very high currents must flow for long times to heat motor windings to the point that they are damaged. However, even very brief high voltage spikes can pierce winding insulation which eventually leads to shorts in the windings and motor failure.

During our conference call with the governor's office, there were concerns expressed about possible increased customer complaints with voltage reduction. This is very real. There are those who will use any change or anomaly in the power system as an excuse to blame the utility for failure of equipment. The fact is that the vast majority of equipment failures, motors in particular, are because the equipment has simply worn out the way car tires and engines wear out. They often die with some last straw (but normal) disturbance the way that most thinning light bulb filaments gasp their final flash when they are hit with the normal surge of current that comes with the switch being turned on. Blackouts are the worse possible situation. Large voltage swings and current surges can occur when all loads on a distribution line must be started at once when power is restored.

I have always felt that the PUC could do more to assist the utilities by educating customers and resolving claims of equipment damaged by service changes. Ratepayers eventually pay for all unreasonable claims. It is quite easy to diagnose the cause of most motor failures, but motors are just thrown away and replaced now days. The serviceperson often just tells the hapless customer that it was the utility's fault. I believe that the PUC could establish criteria for verifying claims, but this would require use of testing centers. There are easy tests for determining the cause of most motor failures (I worked in a General Electric motor warranty and repair center when I was a student).

After the press reports about the transformer load reduction switch that we have been testing, we received hundreds of statements from service people and power system consultants that low voltages on motors and appliances would be disastrous. I finally wrote a short note on the causes of motor failure to answer these concerns for all.

9.1.

This memo was the response from ENERGY COMMISSION Commissioner Arthur Rosenfeld to the surprising announcement by PGE executives at a preliminary CPUC meeting on July 17, 2001, that they could not contribute as much load reduction by EVR as they had promised in June 2001.

Arthur H. Rosenfeld, Commissioner, California Energy Commission
(916)654 4930; Cell phone (telephone number deleted);
Arosnefe@energy.state.ca.us
7-19-01

We at the CEC are surprised that PG&E has stated that their customer voltges are too low to allow them to make voltage reduction enery savings more than 40 megawatts. No mention of widespread low voltages was mentioned by PG&E representatives during many hours of conference calls with the utility, CEC, and the governor's representatives in June 2001. We believe that PG&E can safely make voltage reductions of 2-1/2 percent (3 volts) at the majority of their substations and circuits serving large urban and industrial areas while still leaving customers voltages at or above 114 volts.

It would be helpful at the workshop on Wed. July 25, if all utilities came with measurements of voltages at or near the meter panels of several hundred customers, preferably plotted as a distribution so that one can easily see the fraction of voltages above 114 volts. If the measurements have not been made on hot (high load) days, the data could be corrected for the estimated additional high-load line voltage drop. Thus we could all see for each typical feeder how much the voltage can be dropped, varying from zero for some customers to well over 3 volts for others where the line is now fed above 120 volts.

The utilities could then present a quantitative estimate of the **average** fraction by which voltage can be dropped.

CEC's consultant, Dr. Willard Wattenberg, may be able to bring a sample of voltage distribution from one area in N. California

(end Rosenfeld memo)

9.2.

The principal investigator was asked by Commissioner Rosenfeld to represent the ENERGY COMMISSION at the California Public Utilities Commission (CPUC) hearing (CPUC Rule Making R. 00-10-002 Filed October 5, 2001). The purpose of this hearing was to consider the ENERGY COMMISSION recommendation and the governor's request for a CPUC ruling that EVR must be used by the utilities in future power emergencies. Legal counsel for the ENERGY COMMISSION helped W.H. Wattenburg prepare the testimony given below.

Email July 30, 2001 to:
Arosenfe@energy.state.ca.us,
Kurt.Schuparra@gov.ca.gov,
John.Ballance@sce.com,
SxB4@pge.com (Bhattacharya, Shan),
TMF2@pge.com (French,Tom),
PLee@SDGE.com,
CYWU@caiso.com,
gig@cpuc.ca.gov,
KXD4@pge.com,
FerreeRL@sce.com,
Gary.Tarplee@sce.com,
GrantAL@sce.com,
Aguha@energy.state.ca.us (Ajoy Guha),
Pmcaulif@energy.state.ca.us (Pat McAuliffe),

Response to July 2001 Utility Filings for Emergency Voltage Reduction and Suggested CPUC Orders

Dr. Bill Wattenburg
July 30, 2001

To: California Public Utilities Commission
Re: I.00-11-001 Filed November 2, 2000

I am a consultant to the California Energy Commission (ENERGY COMMISSION). I supervised the tests and measurements this year that led to the recent ENERGY COMMISSION proposal to the Governor that the utilities should implement moderate voltage reduction to avoid possible blackouts in California this summer.

The following paragraphs contain my opinions. These are not the official position of the California Energy Commission or any other government agency.

The 2-1/2% voltage reduction proposal was made for one reason and only one reason: to reduce energy demand during the emergency period this summer in a manner that could avoid some or many blackouts. This proposal was not made to force the utilities to change the long-standing, stable voltages on their distribution lines on a permanent basis nor does this proposal imply that there is anything wrong with present utility line voltages. I supported the original Rule 2 range of 120 volts (+ or – 5%) many years ago because it adds stability to the electrical grid that has served California well for so many years. However, no one anticipated the power shortage situation that exists today.

It must be emphasized that the CEC proposal recommended a very moderate voltage reduction of 2-1/2%, but no less than 117 volts at substations (circuits) and no less than 114 volts at the <u>majority</u> of customer meters. It was recognized that some customers will have voltages lower than 114, and Rule 2 may have to be changed to protect the utilities from liability. It may be sufficient to simply clarify Rule 2 to reflect the intent and spirit of the ANSI standards which recognize that voltages can go as low as 110 volts during emergencies so long as there is a plan to restore minimum voltages at the meters to 114.

This magnitude of voltage reduction is no greater than the normal voltage drop that occurs on many distribution circuits during peak demand times when there is sufficient energy to supply all demands.

Most of the fears expressed by the utilities in their July 2001 filings are appropriate for much larger voltage reductions and/or normal times when there is sufficient energy such that many utility lines could once again be fully loaded by peak demands. It is not expected that we will be in that situation this summer.

Any blackouts that occur this summer will be because there is not enough energy available to overload most utility distribution circuits. Temporary 2-1/2% voltage reduction was proposed to avoid these blackouts.

It was implied in the many discussions with the utilities and the governor's office, but not explicitly stated, that utility voltages should be restored to previous levels following the emergency period. I believe that if the utilities are willing to make this emergency effort, any reduced voltages achieved should not be used by any third party to force the utilities into permanently reducing voltages by claiming tariff violations of some sort.

Southern California Edison has stated that they are willing to reduce voltages that could save as much as 160 megawatts during stage 3 alerts, providing certain reasonable conditions are met. PG&E has stated that they have only 300 circuits out of 3000 that can be reduced to achieve 40 megawatts power reduction for the duration of the hot season. I believe that many more PG&E circuits could be reduced by 1 to 3 volts if this were done in the most expeditious manner (described below) these circuits will not be as low as 114 volt (meter) during peak times because of the continued energy shortage and consumer conservation that will prevail this summer.

It appears that PG&E has selected only the 300 circuits that deliver more than 114 volts at the customer meters and are at more than 120 volts at the substation level during previous peak demand times when energy was abundant and circuits could be operating at maximum current levels. However, they do not state how many of the other 90% of their circuits are at the upper range of 114-120 volts and could be reduced by some amount as proposed by the ENERGY COMMISSION.

The present energy shortage and substantial customer conservation have reduced delivered power levels such that most circuits will not be operating at maximum current levels -- either that or these same circuits were operating way over maximum current levels at peak demand times before the power crisis began last year. <u>The reduced maximum peak current levels on these circuits will more than accommodate the worst fears of current increases due to 2-1/2% voltage reduction.</u>

PG&E states that a computer analysis was used to select the circuits on which voltage can be reduced. Any meaningful computer simulation requires a prior accurate description of the electrical characteristics of every circuit and historical data on its actual performance at various load levels. Hence, they must know the maximum current capacity of each circuit and the maximum loads that it has carried in the past. I believe that a comparison of circuit capacity and expected load levels this summer could identify many more circuits where voltage reduction could be achieved.

<u>Recommended Rule 2 Changes to Allow Emergency Voltage Reduction:</u>

The existing CPUC Rule 2 should be modified to allow the utilities to achieve significant voltage reduction during emergency periods such as this summer without facing unfair liability for doing so.

1. I believe that the missing ingredient is a mechanism whereby the CPUC, the Governor, or some other state authority can declare a "period of power emergency" which then triggers a new set of CPUC rules which will allow (or order) that the utilities make moderate voltage reductions within safe guidelines and which protect the utilities from liability for doing so. The CPUC shall specify the nominal percentage voltage reduction that shall be attempted by the utilities so long as they can stay within the guidelines in paragraph 2 below.
2. The present Rule 2 and any other CVR orders should be modified to be consistent with the full scope and intent of the ANSI standards which clearly spell out that customer voltages can go as low as the level B standard of 110 volts during emergencies so long as there is a plan to restore voltages after the emergency period. Voltages at some customer meters can be allowed to go as low as 110 volts so long as, say, 90% of all customers on a circuit are at or above 114 volts. Furthermore, any customer who complains about a voltage below 114 volts shall

be restored to 114 volts minimum within 3 days by local line correction procedures or the entire circuit voltage must be raised.

3. Utilities can not be held liable for customer claims for equipment damage if they adhere to paragraph 2 above in order to implement emergency voltage reduction ordered by the CPUC.

Reality is that a few customers somewhere are below 114 volts during normal times even when the substation voltage is at the high end of rule 2 (126 volts). A rigid enforcement of the CVR order of 114 to 120 volts at the customer meter such that no customer (not even one) is outside this range is unrealistic and unfair to the utilities charged with supplying adequate service to all customers. Violations can occur anytime there is an unforeseen local disturbance or there is a major circuit outage.

The ANSI standards recognize the above realities with two ranges of acceptable minimum voltages. Level A specifies 114 volts during normal times and Level B specifies 110 volts during emergencies. The CVR standards set by the CPUC are supposed to be based on the ANSI standards. However, some chose to interpret the CPUC CVR standard as if it sets a rigid range of 114 to 120 volts at all times. The ANSI standards say that voltages can go as low as 110 volts in an emergency so long as there is a plan to restore voltage to at least 114 (implying after the emergency has passed). The ANSI standards do not specify any maximum amount of time after which voltage must be restored to 114.

The California Energy Commission obtained opinions from a member of the ANSI committee, Larry Conrad from Cinergy, who stated that ANSI specifies no time-frame on how soon emergency voltages as low as 110 volts must be restored to the level A standard of 114 voltages minimum so long as they are restored after an emergency has passed. He gave the opinion that the time frame could be several months if in fact an emergency, such as the threat of widespread blackouts, exists for that period and some customers have voltages below 114 but not lower than 110. He also pointed out that the ANSI standard does not imply that the majority of customers can be deliberately reduced below 114 volts. His opinion is that voltages should be reduced to the lower end of the 114 to 120 volt range if voltage reduction is necessary to avoid the much more serious consequences of blackouts (see copy of email below from Larry Conrad to Kurt Schuparra dated 7-24-2001).

In summary, a new Rule 2 should recognize reality and specify the percentage of customers who shall have voltages above the ANSI Level A minimum of 114 volts during normal times and during emergencies. During emergencies, the new rule should specify a time frame to restore any customers who formally complain about voltages lower than 114 but above 110. This approach makes it possible to achieve significant voltage reduction during power emergencies while complying with the spirit and intent of the ANSI standards as explained below.

Comments on the Recent Utility Filings on Emergency Voltage Reduction:

Some of the July 2001 utility filings to the CPUC on emergency voltage reduction appear to be more responsive to fending off the latest TURN demands for permanent voltage reduction than they are in addressing the request for emergency voltage reduction to avoid blackouts this summer. This may have been necessary. Forcing unjustified, permanent voltage reduction on a shotgun basis will not improve the long-term quality of service or provide significant real cost savings to consumers when there is once again a adequate supply of energy. And it certainly not the time now for anyone to be hassling the utilities that are having a tough enough time staying in business and supplying energy to California. Any additional expense or effort placed on the utilities now should be directed to solving the immediate emergencies that could occur this summer -- not imagined “tariff violations” based on narrow interpretations of old rules that are too rigid for the realities of today.

Other objections in the utility filings to emergency voltage reduction are based on possible “high current” problems that could only be serious during times of maximum loads on their distribution lines. The very nature of the emergency we face this summer is a shortage of energy which means that most utility lines will not be loaded to maximum levels at peak demand times. The vast majority of distribution lines have been designed to handle, and in fact have carried, peak loads greater than the energy that will be available or the expected demands this summer. Consumer conservation has reduced former peak loads on most lines by 10%. If blackouts occur, it will be because of a shortage of energy for most distribution lines that are carrying less than full capacity. Hence, the chance is very small that overload problems will occur because 2-1/2% voltage reductions cause “current increases” that overload lines that are carrying maximum loads at peak demand times this summer.

The few circuits that could possibly carry maximum loads this summer are well known to the utilities. If this were not the case, the computer models they are using to predict circuit performance would be worthless. The answer to the “high current” argument is the obvious: don’t reduce voltage on the circuits that could be carrying maximum loads this summer. That leaves a few thousand other circuits that can be reduced.

To be sure, achieving stable line voltages is a costly, time-consuming, and continuous process for the utilities. Line voltages can not be changed quickly without some liability to the utilities. CVR regulations should be updated to recognize that any requirement on utilities that voltages must be maintained in an absolute range of 114 to 120 volts at the customers’ meters at all times and for all customers is an unnecessary and unfair burden on the utilities and consumers and that it precludes emergency voltage reduction in the swiftest possible manner. Under present circumstances, such rigidity only opens the door to frivolous litigation and full employment for lawyers who can wallpaper the hearing rooms of the CPUC with shotgun accusations of tariff violations based on no evidence of real problems or significant benefits to consumers.

For instance, there are many situations today in which utility substation or circuit voltages are and must be maintained higher than 120 volts to properly serve some customers with high technology equipment. (This equipment will operate at lower voltages but with a reduced margin of safety.) This means that some customers near a substation will have voltages above 120 volts. On the other hand, there are also many situations in which customer voltages can be lower than 114 volts and the only impact on the customers will be that their meters will not run so fast and they will not be charged for energy that they don't need and cannot use. It is also a fact that even when a substation voltage is at 126 volts, there can be a few customers with voltage at the meter of less than 114.

Anytime substation voltages are reduced for emergency purposes there will be some customers below 114, through no fault of the utility. In normal times, the occasional customer with low voltage is usually recognized by a customer complaint. The utilities usually respond by correcting the customer voltage at the local level.

The filing from Southern California Edison (SCE) recommends that the present Rule 2 (114 to 120 volts) be changed to protect utilities from liability if they reduce voltage to avoid blackouts as requested by the governor. SCE states its willingness to make significant voltage reduction if it has protection from those who might complain if their voltages go below 114 or make claims for equipment damaged due to low voltage. In my opinion, this is reasonable and only fair if the utility makes the effort requested to avoid the much more serious consequences of wide-scale blackouts.

The filing by PG&E opposes any change in Rule 2. But at the same time they argue that only 10% of their circuits are outside the Rule 2 range of 114 to 120 volts and therefore these are the only circuits that they can reduce in voltage for the summer. **They do not state, however, how many of the other 90% of their circuits are at the upper range of 114-120 volts and could be reduced by some amount (but no lower than 117 volts as proposed by the ENERGY COMMISSION).** This rigid interpretation of Rule 2 and/or the ANSI standards means that most of the circuits that could be reduced safely are excluded from consideration.

<u>**Forthright Emergency Voltage Reduction:**</u>

The most forthright and immediate way to find out what can be done is to begin reducing voltages on circuits that are operating at the high end of 114 to 120 and determine if any customers go below 110 – or if any large number go below 114. If so, simply raise the voltage again on this circuit and go on to the next one.

It takes very little time for utility field people to turn down the voltage on any circuit. It takes a lot more time to fine tune the circuit regulators and capacitors for optimum performance during peak demand times. But if there is no great expectation that the circuit will be loaded to full capacity this summer, there is much less need to fine tune the circuit to prevent current overloads after a small voltage reduction.

The reality of reducing voltage to the lower end of the 114- 120 range as suggested by Larry Conrad is that most circuits could be reduced 2-1/2% (or no lower that 117 volts) at the substation level while leaving the majority of customers at or above 114 volts. Some will be below 114 but above 110 -- more than is the case when substation voltages are at 120. But that is the price to be paid to avoid some total blackouts. That is what the ANSI standards allow during emergencies.

For instance, the Lawrence Livermore National Laboratory has been routinely reducing its substation voltage by 2-1/2% during stage 3 alerts this year. It takes ten minutes turning a knob. They achieve the expected power reduction without any necessity to adjust line capacitors because at these times, like most utility lines this summer, they are operating at less than previous peak load capacity. They see a small current increase which is a minor expense compared to the power savings. They have experienced no problems with any of their lines or equipment. They have the most exotic collection of high tech equipment, computers, and sensitive instruments in the world at a vast facility that employs 6000.

SCE reported that they did an experiment in which they reduced voltage by 5% on a major substation serving many distribution circuits. They got the expected power reduction of about 0.4% per volt reduced. It was reported that they received no customer complaints for the duration of the reduction. It is reasonable to expect that they would not receive complaints for the smaller reduction of only 2-1/2% as proposed by the ENERGY COMMISSION. Nevertheless, there were probably some SCE customers below 114 and some even below 110. It is not fair to ask SCE to do this during every stage 3 for the rest of the summer without protection from the CPUC in the form of a rule 2 change and release of liability.

Most of the high-tech campuses in Silicon Valley and elsewhere in the state have their own substations. They will not be effected by voltage reduction on the distribution lines of the utilities. In my survey of line voltages in the north state, I found a few buildings in these campuses that were operating with 114 equivalent because rapid expansion has taxed the capacity of the original distribution lines that were installed years ago. However, they still have a margin of safety before shutdown of their most sensitive equipment because their disconnect voltage is 12% below a nominal 120 volt level (106).

(end Wattenburg testimony)

9.3.

The following report was written as an answer to the many "expert witnesses" at the CPUC hearing on EVR who testified that lowering line voltage to the 117 volt level could cause high currents in motors that might damage the motors. This report was submitted to the hearing officer and all participants (CPUC Rule Making R. 00-10-002 Filed October 5, 2001)**.**

Unreasonable Fears that Motors Will Fail Because of High Currents When Utility Voltages Are Lowered by 2-1/2 Percent From the Present 120 volt Level. Most motors actually run more efficiently because of power factor increases

Dr. Bill Wattenburg
Consultant, California Energy Commission

July 19, 2001

The California Energy Commission has recommended that utility voltages in California be lowered by 2-1/2 % for the summer to avoid potential blackouts. The ENERGY COMMISSION proposal for a 2-1/2 % voltage reduction will move the nominal 120 volt substation level down no more than 3 volts to 117 volts (or 234 volts on "240 volt" motors). Furthermore, the ENERGY COMMISSION proposal states that voltages at the majority of customer meters should be kept at or above 114 volts, which is the minimum recommended by the National Standards Association (ANSI). There is absolutely no danger to industrial and appliance motors with this small voltage reduction compared to the present level of voltages supplied by the utilities. Recent, and rather surprising, test results are given below which demonstrate that quite the opposite is often true. Because voltages are higher than necessary in most places today, the efficiency of many motors actually increases with moderate voltage reduction.

Unfortunately, many service people and electricians believe that even a small reduction of line voltage, no matter how unnecessarily high the voltage may be, will damage motors. This is totally unfounded and unreasonable. Test data given below show that the current drawn by motors can even decrease with moderate voltage reduction when motors are operating at excessively high voltages, as is the case today.

Motor Design:

The present line voltages of 120/240/480 volts are at the high end of the specified voltage range for all industrial and appliance motors manufactured for use in the U.S. All appliances and motors manufactured for the U.S. are designed to operate very well and safely over a range of 105 to 125 volts, and tests show that these motors operate more efficiently and run cooler at the lower end of the voltage range. The same is true for “240 volt” and “480 volt” motors which are designed to operate safely at voltages as low as 200 and 400 volts. So, how could these devices be hurt by reducing voltages down to 117/234/468 volts? The fact is they can’t.

Historically, voltages in the U.S. were in the 110 volt range until utilities began raising their voltages in the late seventies. However, manufacturers have continued to design their appliances and motors to operate well and safely at the lower voltages because many areas in the U.S. and overseas still have customer voltages at or below 110 volts. The same is true for “240 volt” and “480 volt” motors. For instance, a typical “240 volt” air conditioner or pool pump motor is designed to run safely in the range 200 to 250 volts. But, it operates more efficiently (and cooler) at the lower end of voltage, such as 220 volts, than it does at 240 volts.

The absurdity of the “high currents” motor myth is that the percentage current increase in a motor cannot exceed the percentage voltage decrease if the voltage reduction is small and the power drawn by the motor stays the same. The ENERGY COMMISSION proposal for a 2-1/2% voltage reduction cannot cause motor current increases more than 2-1/2 %. Nevertheless, some uninformed alarmists imagine 20, 50 or 100 percent increases in motor currents that will destroy motors. Such large increases in motor currents can only happen as the result of prior mechanical failure in the motor or faulty power circuits to the motor. This happens all the time, but it is not the fault of the utility or moderate voltage reduction.

Efficiency of Motors:

There are good reasons why moderate voltage reduction today saves energy consumed by most industrial and appliance motors. When motors are operated at voltages above their optimum voltage, they operate less efficiently (lower power factor) and they waste more energy in the form of heat.

The most important thing for utilities is that the power factor of most “240 volt” motors improves with moderate voltage reduction below 240 volts such that the line currents supplied by the utility lines actually decrease. This is a very real energy savings.

Recent Test Results:

Recent tests results for a popular air conditioner “240 volt” motor under normal load are shown in the table below. Look at the 3.3% improvement in line efficiency (power factor) when the voltage is dropped only 2% (5 volts) from 240 to 235. Note that when the voltage is reduced by 2%, the current drawn by this popular motor actually decreases from 10.17 amps to 10 amps because of the increase in power factor -- while the power consumed stays almost the same (99.7% of 240 volt power). The motor also runs cooler because of less internal heat loss. This motor is designed to drive the full load of the A/C compressor at voltages as low as 200 volts -- with the best power factor. There is not even a slight increase in motor current until the voltage goes as low as 205 volts.

Loads
Trane
XL1400

Voltage	Current	kW	PF	kVA
240.4	**10.17**	**2.19**	**0.89**	**2.44**
235.4	**10**	**2.16**	**0.919**	**2.35**
229.9	9.88	2.14	0.94	2.27
225.3	9.88	2.12	0.955	2.23
219.8	9.94	2.12	0.968	2.18
215.2	10.01	2.1	0.976	2.15
210.4	10.14	2.1	0.982	2.13
205.1	**10.28**	**2.08**	**0.988**	**2.11**
200.2	10.47	2.08	0.99	2.10

Because of the power factor improvement with moderate voltage reduction, the utility line current for the above motor actually drops. This means a reduction in utility line losses at the reduced voltages – while delivering almost the same real power.

Below is the test data for a larger air conditioner "240" volt motor. The current increases only 1% after a voltage drop of 4% from 239.5 to 230 volts. Again, the power factor and efficiency of this motor increases with voltage reduction (as much as 10% voltage reduction if desired).

Volts	Amps	kW	PF	kVA
239.5	**14.25**	**3.23**	**0.956**	**3.41**
230	**14.4**	**3.21**	**0.971**	**3.31**
220.2	14.71	3.2	0.98	3.24
210.7	15.2	3.15	0.986	3.20
200	**15.87**	**3.13**	**0.987**	**3.17**
220.1	14.68	3.16	0.98	3.23
239.4	14.2	3.25	0.957	3.40

Motor Failures:

There are reasons for the "motors fail because of high currents myth" which are well know to manufacturers and motor design experts (just make a call to any motor repair shop). In 99% percent of all motor failures, the motor fails because some internal component of the motor has failed or worn out. The high currents and high temperatures that the service man sees when he arrives are the result of prior internal failure of the motor or an interruption of the power circuit supplying the motor. Often, the serviceman finds that the motor is stalled, it is drawing high current and the voltage on the motor is very low. This convinces the serviceman that the motor failed because of low voltage that in turn caused high current which in turn "burned up" the motor. It is often easy to tell the customer that his motor failed because of low voltage from the utility. The motor is replaced with a new one. The old one is thrown away before anyone can take it apart and see why it really failed.

Neither the serviceman nor the customer ever learns the truth. (But, interestingly, the serviceman never changes or repairs the power lines feeding the new motor because there was nothing wrong with the line voltage to begin with.)

The most common reason for the failure of single phase 120/240 volt appliance motors is that the starter circuit capacitor or winding has failed. Mechanical failures such as a worn out bearing can cause a short circuit in the windings. The motor is found stalled (unable to rotate) under full load and voltage. This causes high currents and a large drop in voltage across the motor. The high currents are most often the results of motor failure, not the cause. In other words, these motors have simply worn out, like tires and fan belts on cars.

Many 3-phase motors are found to be stalled and overheated. The serviceman often hears the motor "buzzing." This is because it has lost power to one or more phases. In this situation, the motor winding and the stalled rotor are just behaving like a poor transformer. Most transformers buzz if you get up close to them. Usually, the motor needs nothing more than a circuit breaker to be reset and normal power restored. But careless service people will often tell the customer that the utility supplied low voltage and ruined the motor.

Most electrical motors simply wear out the way tires and fan belts in cars wear out. Many car engines burn up because a fan belt fails, the driver continues under full power, the radiator boils over, and the engine heats up and burns up. There was nothing wrong with the major mechanical components of the engine or the speed at which the car was being driven (the voltage). Nevertheless, some mechanics who want to sound smart will tell the hapless owner that he was sold "bad gas" or the car was a "lemon model" -- just so the mechanic can blame someone else and sound like a hero to the owner.

Motors can be damaged by very low voltages (20 to 50 percent drops in line voltage) when they are not properly protected by circuit breakers (wired to code). The ENERGY COMMISSION 2-1/2% voltage reduction proposal cannot cause such large voltages drops.

Motors are Very Tough:

All modern motors must meet UL approval which requires that they can not be damaged by stall conditions due to low voltage. Modern commercial motors are protected by both current limiting breakers and internal thermal switches (this includes modern 240 volt air conditioner and pump motors). If the power service lines are properly wired to code there will be overload protection and circuit breakers to prevent the motor from burning up due to excessive current. No utility can guarantee constant rated voltage at all times. Low voltage due to power line failures and defective wiring in homes occurs frequently. Motors must be able to withstand these anomalies.

Interestingly, most older motors do even better on voltages much lower than the average 120 volts now supplied by most utilities. They were designed with the expectation that they had to operate over a wider range of voltage than normally occurs today. You will find many older motors that specify 100 to 120

volts. These motors have no difficulty operating continuously at a 10% reduction in the normal 120 volt service (down to 108 volts).

Below are sections from a report by the U.C. Lawrence Berkeley Laboratory, June 2001, discussing the voltage reduction proposal by Bill Wattenburg.

All devices using power from the grid have a range of voltage over which they will operate acceptably. **Typically, for motors and appliances designed for nominal 120-volt systems, the design voltage is 115 +/- 10%, or 104 to 127 volts (or 208 to 254 volts for "240 volt" motors and devices).** The design voltage for the device is lower than line voltage to allow for voltage drop between the utility meter and the load.

Different types of loads react to voltage variations in different ways, but in general the power used decreases as the voltage is lowered. Incandescent lighting and resistance heating devices decrease in power with the square of the voltage. Dimmer incandescent lighting might be noticeable. Fluorescent lighting input power drops in an approximately linear fashion, roughly equal to the % voltage drop. But, the lower light level is seldom noticeable for voltage drops less than five percent.

A properly matched motor and its driven load (pump, fan, etc.) operating on a properly designed and installed electrical system will have no problem operating at voltages at 10% (and often more) below their design (which is already 4% below the nominal supply voltage). This includes motor driven appliances (refrigerators, air conditioners, etc.) and the vast majority of other motor applications. But the rare motor that is already significantly overloaded, or that is operating on a circuit with excessive voltage drop or imbalanced voltages in a three-phase system, may trip its overload protection, or in extreme cases, fail to start or remain running under load. Thus, motor users would be well advised to check for overloaded motors or improper voltage conditions. However, lightly loaded motors will run more efficiently and thus cooler and enjoy extended lives under reduced voltage conditions.

Motors with Variable-Frequency Drives will operate with little change, since the VFD isolates the motor from line conditions within the normal tolerance; these loads will draw the same amount of power.

Computers typically are rated to operate on systems as low as 100 volts; they will compensate for the lower voltage and will draw the same amount of power.

The comparison has to be with the consequences of total blackouts.

FAQ's:

1. Why do motors burn out if the voltage is too low? There is a mythology surrounding what happens to equipment at low voltages, and burned out motors is #1 on the myth list. Only improperly applied motors without proper overload protection (violating both manufacturers' application requirements and electrical codes) would be at risk of burning out. All other motors will run fine or, if overloaded, trip their overload protection. Typical

motors will be slightly reduced in input power, since their speed drops slightly and the load on the motor drops as the speed drops. But in rare cases where the output power is held constant, they may run hotter, if operating close to, or above, their rated load; a hotter motor will have a somewhat reduced life. The reason for the hotter operation is that the efficiency drops with voltage for a fully loaded motor as the voltage is dropped. So a heavily loaded motor can typically run hotter. Note that most motors run at significantly below full load; a reduction in their voltage makes them run cooler and thus last longer.

Actual tests for a wide range of motors show that most operate at best efficiency at much lower voltages than being applied today. A typical single phase induction motor tested is most efficient at 220 volts (like 8% voltage drop from 240) with only a 2% power drop, a 3% current increase and an increase of power factor from .96 to .98. It is to be expected. Manufacturers have designed their motors to operate over a wide range of voltages with particular attention to voltages lower than the 120/240/480 levels since this is where the most complaints and failures would come from if they didn't. A motor designed for peak efficiency (lowest power factor and heat generation) at 220 volts will waste energy at higher voltages even though it will put out slightly more power.

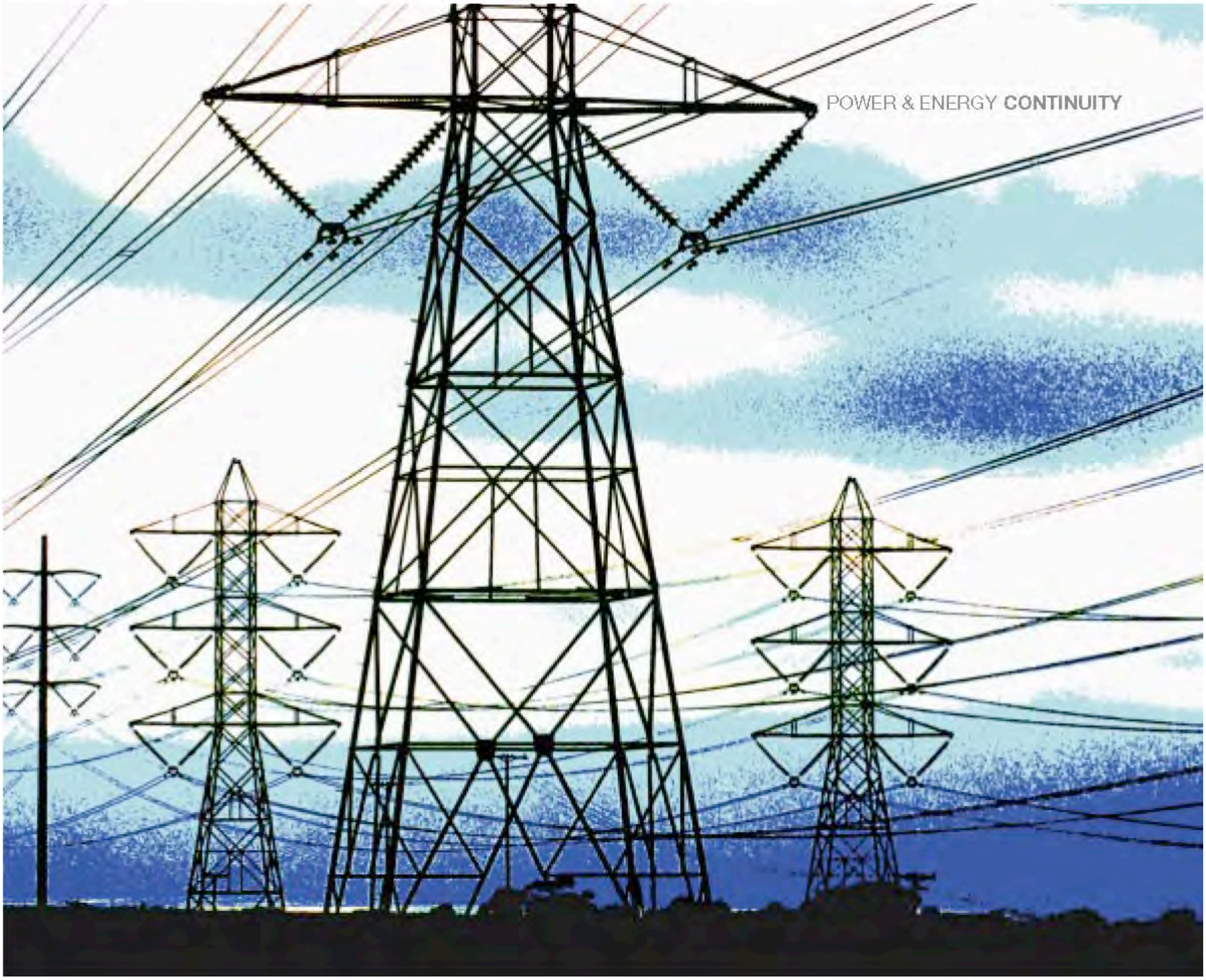
2. What kinds of equipment might be harmed by low voltage? Most equipment will protect itself from low voltage conditions. Equipment life might be shortened or lengthened (see #1). Note that at the proposed voltage levels, only equipment not being used according to its design would have trouble operating or be at risk of damage.

3. Would BART run slower? No. The AC-DC converter stations that deliver power to the BART track can compensate. Even if the track voltage were slightly lower, the controllers on the BART cars would compensate. But escalators and some elevators would run imperceptibly slower.

4. Would lights be noticeably less bright? Incandescent lighting might be noticeable less bright, since their power demand drops with the square of the voltage, and their light output drops faster than the power reduction. The change in light level with fluorescent lighting is unlikely to be noticeable.

5. Would clocks run slow? No, not even the ones connected to the AC system. The electromechanical clocks use synchronous motors, which are locked in to the frequency of the AC power (which will remain constant) and can operate over a wide voltage range at constant speed. Electronic clocks either use the AC frequency as a signal or a chip to generate the time base.

6. Would there be any noticeable effects? Aside from the incandescent lighting, folks may notice that resistance heat devices (electric dryers, electric water heaters, and electric stoves, e.g.) take a bit longer to complete their tasks. This effect will reduce the overall savings somewhat, since if a load is on longer, taken in aggregate across California, more of them will be on at the same time. Most people won't notice a change. But keep in mind, even if people use appliances longer, voltage reduction still reduces the peak demand by lowering the instant power demands.



LIGHTENING **THE LOAD**

by Dr Bill Wattenburg, Consultant, Lawrence Livermore National Laboratories

THERE IS A PROVEN WAY TO AVOID MASSIVE GRID FAILURES WITHOUT WAITING YEARS FOR LONG-TERM GRID IMPROVEMENTS. WE NEED FEDERAL REGULATION OF POWER RELIABILITY AND IT NEED NOT INTERFERE WITH ECONOMIC DEREGULATION.

Immediately after the massive northeast blackout of 14 August 2003, several top scientists and government officials who know the experiments and the plans that were implemented during the California energy crisis of 2000-2001 suggested that I prepare this report on electrical grid protection for officials in Washington who must set policy in the future. What I say here is not speculation. It is backed up by major experimental and operational results.

Anytime there is a major disturbance at any place on the grid, there must be immediate, pre-planned load reductions in all regions of the grid to guarantee that power plants and transmission lines will not be overloaded. This is why they slow down all the race cars when there is an accident on the track. Trying to contain an unknown major disturbance to only one region of a large, heavily loaded grid is often futile or foolish, as the northeast blackout of 8/14 demonstrated.

Emergency load reduction was used in California in 2001 by ordering all local utilities to immediately execute pre-planned, selective blackouts. But we learned that there is another way that is painless and does not disconnect anyone. With minimal preparation, utilities can immediately reduce line voltages wherever they are above 110 volts (most are at 120+ volts). This can painlessly relieve a large amount of load on almost any grid.

Either or both of these emergency procedures reduces the load everywhere on the grid and provides a cushion so that power plants on the grid can safely absorb greater transient swings in voltage, current and power demand without immediately switching offline to protect themselves. Grid managers usually have emergency load reduction plans of some sort. But these are seldom tested or practiced for readiness on a grid-wide basis. When the grid is collapsing, there is no time to improvise.

During the California energy crisis, pre-planned selective blackouts left all essential communication, transportation, police and health facilities operating. We next proved that load reduction by immediate small voltage reduction can do the same without denying service to anyone. This avoids blackouts.

These two forms of emergency response can be ordered and implemented nationwide in a matter of months. Granted, most grids require major improvements. But the country does not have to wait five years for major infrastructure improvements to prevent existing grids from collapsing as happened on 8/14.

We must have federal regulations that require minimum reserve capacity for all power grids in the US. The rule should be that no power plant or major transmission line can be loaded to more than 85 to 90 percent capacity for more than, say, one percent of the time during a year. This one percent will cover all expected power emergencies that typically last a few hours a year. The deadline for compliance should be no more than five years from now.

This rule will give clarity and stability to all deregulated power company investors and owners. It will knock off the political bickering and environmental obstructionism in the various states because all utilities and power companies will be required to upgrade to meet these very reasonable and necessary federal standards. This rule does nothing more than require the degree of reserve capacity that the original regulated utilities were required to maintain for decades – indeed, ordered to maintain by state public utility commissions.

Immediate, adequate protection of the US electrical grids can only be done by emergency federal regulations or federal law because the power industry lobby has opposed comprehensive emergency regulations at the state level.

“Granted, most grids require major improvements. But the country does not have to wait five years for major infrastructure improvements to prevent existing grids from collapsing as happened on 8/14”

While most of our utilities are using the best quality equipment available because it is the most profitable, they are not making good use of the equipment and technology to prevent major system failures.

BACKGROUND

California’s energy crisis of 2000-2001 allowed us to conduct experiments to prove the above concepts. Pre-selected rolling blackouts across the entire grid system were used in California to reduce loads and prevent power plants on the grid from being overloaded. We then proved that the utilities could reduce voltages to customers by up to five percent without any noticeable reduction in service or damage to customer equipment. This removes the necessity of using rolling blackouts during most power shortages or grid emergencies. Five percent voltage reduction instantly reduces the power demand on a typical loaded grid by two percent. This is the equivalent of one or two power plants on a large grid. No one loses service with small voltage reduction.

THE EXPERIMENTS

The California Energy Commission asked myself and the Livermore Lab to investigate ways to reduce demand on the California grid to avoid the blackouts. A team of experienced power system and transmission line engineers was assembled. During the spring of 2001, we conducted around-the-clock experiments at the PG&E High Voltage Transmission Tech Center in San Ramon, California.

We did real voltage reduction experiments on the transmission lines serving hundreds of thousands in the Los Angeles area during peak load times. Some utility engineering managers insisted these experiments would not work. But they agreed to carry them out under emergency request from the state. Line voltages were dropped five percent for several hours during afternoon peak hours. The experiments worked. We achieved the power reductions we predicted (however, we had to show the utility company engineers how to adjust their own equipment to achieve real power reductions with voltage reduction).

The biggest surprise came from the greatest load on our power grids during summertime: home air conditioners. Comprehensive tests showed that the most popular home air conditioners are most efficient at around 200 volts, not the standard 240 volts. (These were tests of total thermal efficiency, not just motor efficiency). This means that an enormous amount of energy is being wasted on our power grids during peak demand times in the summer. It also means that the loads on electrical grids can be lowered substantially and immediately during power emergencies so that power grids do not collapse. The experimental data is available at the California Energy Commission.

In several meetings with the California Energy Commission during June 2001, the top officials of the three major California utilities agreed that emergency voltage reduction could do away with having to order rolling blackouts during power shortages. However, after the energy crisis was over, the utility companies suddenly reversed field and devoted enormous legal effort to defeat California Public Utilities Commission orders that would require the utilities to use emergency voltage reduction in any future energy crises. This was curious because many east coast utilities have voltage reduction plans approved and in place to reduce excessive demand at any time. ■

Dr Bill Wattenburg is a research scientist at the Research Foundation, California State University, Chico; a consultant for the University of California Lawrence Livermore National Laboratory; a former nuclear weapons designer at the Livermore Lab, and a former member of the US Air Force Scientific Advisory Board. He is host of the 'Open Line to the West Coast' show, KGO Radio AM810, ABC Network, San Francisco (since 1972). For more information please visit www.drbill.org or email wattenburg@aol.com He can also be contacted through the California Energy Commission.

COMMENTS TO FEDERAL OFFICIALS INVESTIGATING THE NORTHEAST BLACKOUT,

SUBMITTED BY THE AUTHOR ON 18 AUGUST 2003.

Grid managers today try to isolate the region where a disturbance occurs and confine the problem to that region. The attitude of other regions on the grid is ‘why should our customers by punished if we are not having problems?’ So they don’t plan for immediate widespread load reduction as a precaution. As a result, it is too late when they realize that the disturbance has propagated to their regions and their power plants are in danger of overload. Then distant power plants disconnect and the entire grid collapses.

After all the arm waving, finger pointing and nonsense testimony is over, you will find that the above is what happened on 8/14. It will happen again soon if the federal government does not take charge and issue regulations for emergency procedures to protect all electrical grids in the US.

The utility industry is going to tell federal agencies and congress that they have determined what caused the northeast blackout of 8/14. They will give assurances that they can prevent it from happening again. This will be nonsense. No one understands the dynamic characteristics of electrical grids this size. So much equipment has been added to these grids that it is virtually impossible to analyze their dynamic response under loaded conditions when an emergency occurs. The only way it can be understood is by doing failure experiments on the grid by disabling major transmission lines and power plants when the grid is loaded and measuring the response of the grid at all locations. But utilities will not disconnect their customers to allow anyone to do such experiments. So only Mother Nature does the experiments for them – when they least expect it and never understand it.

The old, regulated integrated utilities used to concentrate on grid reliability first and foremost. That was the golden rule. The individual utilities don’t do this now because so many of the power plants are owned by others. There is no coordination and overall authority for emergencies. The bean counters who run the utilities and the power plants today refuse to do real grid failure tests at normal times because they don’t want to inconvenience customers and lose the income. Instead, they all read from old cookbooks that say everything will be ok if they do certain things. But our electrical grid systems have become vastly more complex than when the cookbooks were written 40 or 50 years ago.

I will bet that the Northeast Grid Reliability Committee (NERC) didn’t test any adequate emergency plans to isolate transmission line disturbances on the northeast grid so that distant power